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CALIBRATION AND QUALIFICATION TESTS
OF McCULLOCH YO-100-4 ENGINE
FOR ROTORCYCLE USE


FINAL REPORT ON
BUAER PROJECT TED NAM-PP-2648.1
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CALIBRATION AND QUALIFICATION TESTS
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Final Report NAMC-AEL-1625
on
BUAER Project TED NAM-PP-2648.1

ABSTRACT

↙ Average results of calibration tests of two McCulloch Motors YO-100-4 engines, mounted at 15 degrees from the vertical position to simulate the installation in the XRON helicopter, indicate that the maximum power output obtainable is 58.6 bhp. This power is 2.3 percent less than the manufacturer's specified rating of 60 bhp at 4000 rpm. The hand starting system proved inadequate, as it did not provide sufficient torque for consistent starting. A foot treadle arrangement, and special shut-down cleanout procedure were required for successful starting. Tests were terminated after three major failures prevented completion of the required 100-hour endurance test. It is concluded that the McCulloch Motors YO-100-4 engine, in its present state of development, is not sufficiently durable for its proposed use as a power plant for small man-carrying helicopters.

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ii

TABLE OF CONTENTS

<u>TITLE</u>	<u>PAGE NO.</u>
LIST OF PLATES	2
INTRODUCTION	3
SUMMARY OF RESULTS	3
CONCLUSIONS	3 - 5
RECOMMENDATIONS	5
DESCRIPTION	5 - 7
METHOD OF TEST	7 - 8
ANALYSIS OF RESULTS AND DISCUSSIONS	8 -14
REFERENCES	15
APPENDIX 1	A1-1 - A1-2
APPENDIX 2	A2-1 - A2-2

LIST OF PLATES

<u>TITLE</u>	<u>PLATE NO.</u>
McCulloch YO-100-4 Engine, Mixture Control Runs	1
McCulloch YO-100-4 Engine, Endurance Runs	2
McCulloch YO-100-4 Engine, Side View	3
McCulloch YO-100-4 Engine, Rear Side View	4
McCulloch YO-100-4 Engine, Showing Fluid Coupling and Cooling Fans	5
McCulloch YO-100-4 Engine, Test Cell Installation.	6
Test Cell Foot Treadle Starting Device	7
Second Failure of No. 4 Cylinder Retention, Engine Serial No. 431-C-3 (Rebuilt), 21.5 Hours Endurance Time	8
Second Failure of No. 4 Cylinder Retention, Engine Serial No. 431-C-3 (Rebuilt), Loose Cylinder Hold Down Nuts, 21.5 Hours Endurance Time	9
Failure of Right Hand Cooling Fan, Engine Serial No. 431-C-3 (Rebuilt), 21.5 Hours Endurance Time, (Secondary to Cylinder Failure)	10
Third Failure of No. 4 Cylinder Retention, Engine Serial No. 431-C-3 (Rebuilt), 25.5 Hours Additional Endurance Time	11
Typical Failure of Exhaust Collector Manifold	12
View of Overspeed Governor Control	13
McCulloch YO-100-4 Engine, Exploded View of Power Section Components	14
McCulloch YO-100-4 Engine, Exploded View of Components	15

I. INTRODUCTION

In accordance with reference a, a test program consisting of a sea-level power calibration and qualification testing of a McCulloch Motors YO-100-4 engine was initiated at the Aeronautical Engine Laboratory. The primary purpose of the test was to determine the feasibility of using this engine as a power plant for the Gyrodyne helicopter now under development for the Navy. Reference a stipulated that the endurance test was to consist of two 50-hour periods of cyclic operation with a complete teardown inspection after the completion of each period. Because of repeated failures, however, the endurance tests were terminated and the engines were returned to the manufacturer, as directed by reference b, for installation of a modified crankcase and other design changes. Subsequently the project was cancelled by reference f.

II. SUMMARY OF RESULTS

- a. A brief sea level power calibration, consisting of fuel mixture control runs at 4000 rpm with throttle adjustments, was conducted at the Aeronautical Engine Laboratory, using a water brake dynamometer for power absorption. Calibration results show that the engine does not meet the manufacturer's specified rating of 60 bhp at 4000 rpm. Maximum power obtainable with carburetor adjustments for optimum mixture distribution and with power corrections applied for carburetor air temperature and pressure deviations from standard conditions was 58.8 bhp with engine serial No. 431-C-1, and 58.4 bhp with engine serial No. 431-C-3 (rebuilt). When individual stub exhaust stacks, locally fabricated, were used in place of the exhaust manifolds supplied by the manufacturers, brake horsepower readings as high as 61 bhp at 4000 rpm were obtained.
- b. Engine durability was demonstrated to be inadequate. Three failures of the retention of No. 4 cylinder to the crankcase occurred during the attempted 100-hour endurance test and resulted in termination of the tests. Failures of engine components (exhaust manifolds, fan pulley, overspeed governor) were also experienced.
- c. Engine starts could not be made with the starting cable pulled by hand. It was necessary to devise a foot treadle starting system that permitted a greater starting torque to be applied than that possible with the conventional "hand-pull".

III. CONCLUSIONS

- a. The calibration results, shown on plate 1, indicate that the engine does not meet the manufacturer's specified power rating of 60 bhp at 4000 rpm employing the regular exhaust manifold configuration. The results of mixture control runs, with all powers corrected to standard sea level conditions, are shown in the following table:

Engine	RPM	MAX BHP	FUEL FLOW LB/HR	SFC* LB/BHP-HR
431-C-1 (Full Throttle)	4000	52	43	.83
431-C-1 (Throttle 9° Past Full)	4000	58.8	40.5	.69
431-C-3 (Rebuilt) (Throttle 9° Past Full)	4000	58.4	42	.72
431-C-3 (Rebuilt) (Throttle 9° Past Full, Stub Stacks)	4000	61	43	.71

*Mfr. SFC Guarantee - .82

As indicated, higher power was consistently obtained because of distribution effects when the throttle was advanced through full throttle to 9 degrees beyond the wide-open setting. The substitution of stub exhaust stacks for the exhaust manifolds resulted in an additional increase in engine power, exceeding the manufacturer's guaranteed value.

b. The endurance quality of the engine is inadequate because of three failures of the No. 4 cylinder retention system. These failures occurred at 26.5, 21.5, and 25.5 hours of endurance on the No. 4 cylinder assembly. The engine manufacturer's recommended corrective action of strengthening the crankcase (see reference d) is endorsed; however, other improvements, such as, stud design, material changes, and a positive locking of the cylinder holddown nuts, appear warranted. See paragraph VIId(2) for discussion of details.

c. Other failures occurring during the tests were:

(1) Failure of the propeller shaft at 10.7 hours of total engine time. Investigation disclosed that the engine rear mounting spacers were too long for proper dynafocal pinch and thus allowed excessive engine movement. The spacers were manufactured by the Gyrodyne Co. to a McCulloch drawing dimension which was in error. Cutting 1/16 inch off the two spacers proved satisfactory. The fluid coupling adapter-propeller shaft taper fit was also unsuitable and the second propeller shaft taper was lapped to obtain a proper fit. A total of 113 hours of operation proved that the foregoing fixes were satisfactory.

(2) Exhaust manifold failures occurred repeatedly throughout the testing.

(3) Carburetor flooding and malfunctioning was experienced frequently during the early stages of the tests.

(4) A fan pulley failed at four hours total endurance time on one test attempt.

(5) Two overspeed governor controls failed because of insufficient bearing lubrication. These controls were designed for horizontal installation and are not adequately lubricated in the proposed flight position.

(6) One coil of a magneto failed and was checked at an emf of 5000 volts compared to 17,000 volts for the mating coil.

d. Numerous difficulties were experienced during attempts to start the first test engine by the hand-pull system. It is to be noted that this engine was designed basically as a target drone power plant with the rotary valve timing optimized for full throttle operation. The target drone engines are started by auxiliary starters. The valve timing is not satisfactory for starting with the hand-pull. A foot treadle and seat arrangement was locally manufactured (see plate 7) and used to provide adequate torque for starting. A special engine shutdown cleanout procedure (see paragraph VIIa) was also required to achieve successful starts.

e. Engine operation was generally smooth and satisfactory throughout all the tests. Adequate cooling air was supplied by the engine's two integral fans.

IV. RECOMMENDATIONS

a. The McCulloch YO-100-4 engine is not recommended for its intended use as a power plant for man-carrying vehicles because of the unsatisfactory reliability exhibited during endurance tests at the Aeronautical Engine Laboratory.

b. A rating of 58 bhp at 4000 rpm under sea level standard conditions, based on the calibration of the engines conducted at the Aeronautical Engine Laboratory, is recommended in lieu of the manufacturer's guarantee of 60 bhp.

c. The hand-starting system of the McCulloch YO-100-4 engine is entirely unsatisfactory and therefore is not recommended for use in service. A foot treadle arrangement provided adequate starting torque; however, an electrical starting system would be preferable.

V. DESCRIPTION

The following is a brief summary of the characteristics of the YO-100-4 engine, (also see reference c). Plates 3, 4, and 5 are general views of the engine.

a. Manufacturer

Name - McCulloch Motors Corporation
 Location - Los Angeles 45, California

b. Model and Rating

Model - YO-100-4
 Type - Reciprocating, air-cooled, two-cycle, four-cylinder,
 horizontally opposed, gasoline engine, with two
 integral cooling fans and a fluid coupling drive.

Engine Nos. 431-C-1 and 431-C-3
 Rating (Manufacturer's)

Rating	Output		Altitude Ft.	SFC Lb/BHP-Hr	Max. Allow. Head Temp. °F
	BHP	RPM			
Take-off	60	4000	0	0.82	500
Normal	60	4000	0	0.82	500
85% Normal	51	3790	0	0.87	475

c. General Description

Number of cylinders	4
Cylinder arrangement	Horizontally opposed
Bore and Stroke, in.	3 3/16 x 3 1/8
Displacement, cu.in.	100
Length, in.	28.0
Width, in.	28.0
Height, in.	16.6
Weight, lb.	
Engine (Including components)	105
Additional Equipment	
Fluid coupling (with fluid)	23
Exhaust manifolds (2)	2.5
Compression Ratio	7.80 to 1
Power take-off	From a flange on the end of the fluid coupling output shaft.
Fuel	Specified: Mixture of MIL-G-5572B, Aviation gasoline, Grade 100/130 and Lubricating oil, MIL-L-6082B, Grade 1065, premixed to a ratio of 10 parts fuel to 1 part oil by volume. Grade 115/145 fuel, premixed with Grade 1065 oil, in the foregoing ratio, was employed for the tests

d. Ignition

Energy source	McCulloch Magneto (2 coils)
Spark plugs	Four BG Model RB916S
Firing Order	The distributor is part of the magneto assembly and is designed to fire nos. 3 and 4 cylinders simultaneously at 180 degrees of crankshaft rotation after nos. 1 and 2 cylinders fire simultaneously.
Timing	25 degrees BTC at full throttle. Spark advance (rotation of magneto) is linked with the carburetor throttle system, advancing the spark when the throttle is opened.

e. Carburetor

Manufacturer	Tillotson
Model	OM-4
Type	Float type, horizontally side mounted on vertical engine.
Fuel pressure	4 to 7 psig

f. Lubrication

Lubricated internally by passage of the fuel - oil mixture (described above) through the crankcase to the cylinder intakes.

g. Governor

Overspeed control device, belt driven, moves throttle toward closed position above pre-set, spring adjusted, speed limit.

h. Starting

Manual starting mechanism consists of steel cable, rewind-spring, racket assembly and related parts.

VI. METHOD OF TEST

a. Testing of the McCulloch YO-100-4 engine to simulate the engine installation in the Gyrodyne Co. XRON helicopter was conducted in accordance with reference a.

b. The engine was installed with the requested nose-up attitude in dynamometer test room 3W of Building 599, Aeronautical Engine Laboratory to perform the endurance and calibration tests. Plate 6 shows a general view of the test installation. The engine was rubber shock mounted to a plate rigidly mounted at 15 degrees from the vertical position. The engine mounting structure and rubber mounts were supplied by the Gyrodyne Co. Two Moreflex rubber couplings at each end of a short power transmission shaft were employed between the engine fluid coupling and the power absorption water brake dynamometer. No additional flywheel was used because the engine's integral fluid coupling acts as a flywheel.

c. A modified Industrial Engineering Co., model No. WA-250 water brake dynamometer absorbed the power for all engine running. Water brake loading was controlled by setting the water level in the brake's closed loop system by means of adding or subtracting water of the system by solenoid operated valves. Water brake torque is sensed by a Hagan "Thrustorq" unit which pneumatically transmits pressure signals to a calibrated Heise gage in the control room. The torque measuring system was periodically calibrated by hanging dead weights (over a pulley arrangement) at the one-foot station of the water brake torque arm. A tachometer-generator mounted on the shaft of the water brake transmits the rotational speed signal to a chronotac indicator. An ILS overspeed ignition cut-off device was also incorporated as a safety feature. The engine is equipped with an overspeed governor control (see general description) which was disconnected during a major part of the tests conducted at the AEL, (see paragraph VIId(4)(d) for discussion).

d. The closed loop water brake system used is similar to the system developed for testing the Nelson H-59A engine. (See reference e.)

e. The fuel and oil mixture was gravity fed to the engine fuel pump. The fuel, Aviation gasoline, Specification MIL-G-5572B, grade 115/145, was mixed with lubricating oil, Specification MIL-L-6082B, grade 1065, blended in a ratio of 10 parts of fuel to one part of oil by volume.

f. The engine was cooled with ambient air supplied by the two integral cooling fans of the engine. The test room air blower was employed to clear the immediate area surrounding the engine of exhaust gases.

g. A standard complement of instruments was used to measure the engine temperatures and pressures. Two thermocouples were installed on each spark plug gasket such that an engine shutdown would not be necessary in the event of a broken thermocouple lead.

h. Temperature controlled and dehumidified air at sea level standard conditions was used when available. At other times the engine power output was corrected to the standard sea level pressures and temperatures

i. The test cycle schedule prescribed for the engine is stated in paragraph VIIc.

VII. ANALYSIS OF RESULTS AND DISCUSSIONS

a. Two new McCulloch Motors YO-100-4 engines, serial nos. 431-C-1 and 431-C-3, were received at the AEL for test purposes. Considerable difficulties were experienced during attempts to start the first engine (serial No. 431-C-1). After many ineffective adjustments to the fuel and ignition systems, the engine was removed from the test set-up and the second engine (serial No. 431-C-3) was installed. At the manufacturer's suggestion, hand-pulling of the starter cable was discontinued and a starting device was fabricated to enable the test mechanic to push both feet against a treadle (see plate 7) to apply a much increased starting

torque. The starting device incorporated at the AEL is impractical for field application; however, it is possible that a modified version of the foot treadle starter can be used in the field. A portable or battery powered electric starter may also be a solution to this problem. However, the former will not permit engine starts in remote areas and may defeat the purposes of the helicopter, while the latter will increase the engine weight. A contributing factor to the hard starting of this engine is that the engine is basically a conversion of the O-100-2 target drone engine and the unmodified rotary valves are timed for optimum performance in the high power and high speed range. When the foot treadle was used, consistent starting was generally obtained provided that an engine cleanout (at the previous engine shutdown) and a particular starting procedure were adhered to on each occasion. The cleanout procedure at engine shutdown consists of the following four steps:

- (1) The throttle is retarded to the idle position.
- (2) The fuel supply valve is closed.
- (3) The throttle is advanced to scavenge the remaining fuel in the carburetor, fuel line, and crankcase.
- (4) The ignition is cut off after the engine stops.

The starting procedure is as follows:

- (1) A small quantity of fuel for priming.
- (2) The throttle is advanced to full open*.
- (3) A series of foot treadle "pushes" in rapid succession until the engine fires.
- (4) The throttle is moved to the idle, (partially open) position immediately when firing commences.

*Full open throttle position is 9 degrees beyond the maximum wide open setting for maximum power.

b. Plate 1 shows the BHP, SFC, and individual cylinder head temperatures versus fuel flow at 4000 rpm for engine serial No. 431-C-1 and the engine (designated 431-C-3 (rebuilt)), assembled at the AEL from components of the two engines (serial No. 431-C-1 and -3) received. The two plots of data obtained from engine serial No. 431-C-1 show the effect of the fuel-air mixture on the distribution pattern to the cylinders and the increased power resulting from opening the idle fuel jet and adjusting the throttle opening 9 degrees beyond the wide-open position. This idle adjustment and throttle opening for optimum power were determined and set with the advice and cooperation of the engine manufacturer's representative. In the early stages of the test program, the carburetor float control and idle adjustment were by-passed and fuel was piped directly to the discharge tube so that fuel flow was metered by a needle valve in the control room. This by-pass system was installed to avoid fuel flooding of the cylinders which had been experienced while starting the engine and also to attain steady fuel flow while conducting the fuel metering tests. The Nos. 1 and 2, upper cylinders (with the engine in a near vertical position),

were running lean, while the Nos. 3 and 4, lower cylinders, were rich, as indicated on plate 1. This condition is attributed to the principle that the fuel droplets, being more dense than the air in the fuel-air mixture, descended by gravitation to the lower cylinders. Another factor is that the carburetor fuel discharge tube is located just upstream and very close to the throttle butterfly valve when the valve approaches the wide-open position. Near the wide-open position, any change in the angle of the butterfly valve markedly affects the distribution of the mixture to the cylinders by deflecting the mixture as the fuel leaves the carburetor fuel discharge tube. Opening the throttle beyond the wide-open position tends to even the distribution of fuel by deflecting the fuel-air mixture upward and therefore increasing the proportion of fuel delivered to the upper cylinders. A throttle opening of 9 degrees beyond the wide-open position was determined to be optimum. In addition, the idle fuel discharge jet is located in the upper part of the carburetor air passage (a side mounted type carburetor) and when adjusted to a rich setting, assists in enrichening the fuel-air distribution to the upper cylinders. This adjusted fuel-air distribution results in a power increase of as much as 13 percent (from 52 to 58.8 bhp). The maximum sea level corrected power at 4000 rpm was approximately the same for both engines Serial No. 431-C-1 and 431-C-3 (rebuilt) (58.8 and 58.4 respectively). Neither engine, with the exhaust manifolds, delivered the manufacturer's guaranteed power value of 60 bhp at 4000 rpm. Also shown on plate 1 are three test points taken during the endurance phase of testing on engine serial No. 431-C-3 (rebuilt) with stub exhaust stacks locally manufactured to replace the exhaust manifolds supplied with the engine. The engine power of these points averaged 60.8 bhp. This increase of power may be attributed to an increase of volumetric efficiency by better scavenging of the exhaust gases.

c. Reference a stipulates that the endurance test was to be composed of two 50-hour periods of cyclic operation with a complete teardown inspection of the engine components after each period completed. The engines were operated to the following cyclic schedule:

- (1) Start and hold for one minute at idle speed (1600 rpm).
- (2) Ten minutes at normal rated power--full throttle (maximum obtainable power at 4000 rpm).
- (3) Eight minutes at 85 percent normal rated power.
- (4) Ten minutes at normal rated power.
- (5) One minute at idle speed.
- (6) Engine cleanout and shutdown.

Plate 2 shows the maximum brake horsepower, specific fuel consumption and cylinder head temperature values at 4000 rpm obtained at each half-hour cycle of the endurance runs. Also shown on Plate 2 are numerical symbols indicating notable conditions existing, changes made, and failures experienced during the cyclic endurance tests. Symbol (1) designates values obtained at 4000 rpm during 33 hours of total engine running time of Serial No. 431-C-1. These 33 hours were used attempting

to achieve the manufacturer's specified power rating (60 bhp) and other operational tests to determine engine characteristics; therefore, it was deemed compensatory to credit the engine with 15 hours of endurance time. Other details of operating conditions are covered fully in the other sections of this report. Although maximum power obtainable with the exhaust manifolds was slightly over 58 bhp, powers were near 56 bhp on a large portion of testing on engine Serial No. 431-C-3 (rebuilt) as shown on Plate 2. Using stub stacks (10 to 16 hours and 42 to 47 hours) on engine Serial No. 431-C-3 (rebuilt) powers exceeding 60 bhp at 4000 rpm were obtained.

d. The engine failures and other operational difficulties experienced during the test program are summarized as follows:

(1) A propeller shaft failure occurred early in the test program on engine Serial No. 431-C-3 after 10 hours of operation. A full metallurgical report of this failure is included as appendix 1. It was determined after this failure that the lower main dynafocal mount spacers (supplied by Gyrodyne Co. to McCulloch drawing dimensions) were too long to allow a proper dynafocal pinch in the rubber engine mounts. The resulting loose mounting of the engine caused additional bending moments in the crankshaft, which compounded with torsional stresses inherent in the engine, contributed to the failure. An additional unsatisfactory condition was heavy galling on the mating surfaces of the propeller shaft taper and the fluid coupling adaptor. Inspection of the mating surfaces of the second engine, Serial No. 431-C-1 showed an unsatisfactory fit, with approximately a 50 percent contact area. These two unsatisfactory conditions were rectified by cutting 1/16 inch from each rear mount spacer, and lapping the propeller shaft taper and the fluid coupling adaptor to provide approximately a 95 percent area of contact. A total of 113 hours running time on the Serial No. 431-C-1 crankshaft has proven these changes to be effective.

(2) There were three failures of the retention system of no. four cylinder to the crankcase.

(a) The first of these failures occurred at 26.5 credited endurance time on engine Serial No. 431-C-1, although a total of 58.2 hours had been accumulated on the engine. Appendix 2 is a report of a metallurgical investigation of the failure. It is concluded in appendix 2 that the failure originated with a fatigue failure of a stud which led directly to the destruction of the cylinder and crankcase. The engine manufacturer was informed of these findings and he stated (see reference d) that crankcase deflections may have caused overstress on the retention studs. After the manufacturer had conducted strain gage tests on the crankcase, he recommended that the crankcase be redesigned to increase the rigidity of the structure. A reenforced crankcase, providing a more uniform load distribution, could be a solution to this problem.

(b) The second of these failures occurred on engine Serial No. 431-C-3 (rebuilt) (this engine was built-up at AEL of parts from the two engines, Serial Nos. 431-C-1 and 431-C-3, received for the test), after 28.3 hours total operating time (21.5 hours endurance time). In addition to a sheared stud, two fiber lock nuts were found loose on other studs, and the No. 4 cylinder was cracked at the base (see plates 8 and 9). A more positive locking device, possibly castellated nuts with safety wire or cotter pins, would be more effective than the fiber nuts. A secondary failure, the right hand cooling fan (see plate 10), also occurred at this time and it is believed directly attributable to the severe vibration induced by the cylinder failure. The sheared stud was replaced; another cylinder, rod, piston, and cooling fan were installed and tests were resumed.

(c) The third failure consisted of a single broken stud of No. 4 cylinder occurring after 25.5 additional hours of endurance time on the rebuilt, Serial No. 431-C-3, engine after the second failure. This stud failure was found during a periodic inspection, between runs of the engine, before damage progressed beyond the stud. The stud had sheared in the crankcase threads about two threads beneath the mating surface (see plate 11). It was observed upon removal of several studs from the crankcase that two studs backed out at approximately 30 inch-pounds torque. These studs should have been installed to at least 175 inch-pounds torque. Other stud breakaway torques measured approximately 200 inch-pounds. Obviously loose studs are highly unsatisfactory as they often cause deflections and oscillatory loads which greatly increase the stresses in the companion studs.

(d) Structural experts of the Aeronautical Structures Laboratory were consulted for information of strength and materials of studs to seek recommendations for better material and stud design. Tests were conducted to determine the ultimate and shearing stresses of three studs removed from the crankcase. Spectrographic analysis of the studs by the Aeronautical Material Laboratory indicated the material is SAE 4140 steel; however, hardness tests indicate a tensile strength of only 120,000 psi, and static tensile stress tests were approximately of the same stress values. The stud threads appear to be rolled, a desirable feature which work-hardens the threaded areas and reduces notch effects. As all stud failures were of fatigue nature, the important feature is to increase the fatigue life of the stud. Handbook values of SAE 4140 steel, for this small diameter, indicate it can be easily heat-treated to 160,000 psi by tempering at 1000°F and quenching at 1525°F. From the standpoint of good fatigue life with good impact resistance, a value of approximately 150,000 psi is recommended. A smooth neck-down section, replacing the constant area between the threads, reduces the thread stresses and increases the fatigue life. Use of the neck-down section is common practice on high strength studs and cap screws. Increased radii at the thread roots also increase fatigue life of the studs.

(3) Because of the three failures of No. 4 cylinder retention system, corrective action is mandatory. The stiffening of the aluminum crankcase, as recommended by the manufacturer, is endorsed providing that the over-stresses of the studs are the result of crankcase deformations. In addition, it is believed that positive locking of the cylinder holddown nuts should be incorporated and stud installation methods improved to prevent stud loosening. One method of improving stud installation would be to incorporate helicoil or other steel inserts in the crankcase. These latter recommendations would not appreciably increase the cost or weight of the engine.

(4) Additional unsatisfactory conditions encountered during the test program are as follows:

(a) The exhaust manifolds cracked or ruptured several times. A typical failure is shown on plate 12.

(b) Considerable malfunctioning of the carburetor was experienced in the early stages of the tests, including flooding of the carburetor caused by the ram effect of the conditioned air, piped to the carburetor as standard procedure for engine calibration. The carburetor float bowl is vented to the air passage at the base of the fuel discharge tube, and air pressure above atmospheric forces additional fuel from the discharge tube. The angle of the throttle butterfly is very critical on fuel distribution and power output as discussed above in paragraph VIIb.

(c) A cooling fan pulley failure occurred after 4 hours total time on engine serial No. 431-C-1. The half of the pulley mounted on the fan in front of No. 1 cylinder cracked at the mounting holes.

(d) Two overspeed governor control failures were attributable to insufficient bearing lubrication. The overspeed governor control was designed for a horizontal mounting position of its shaft. Oil in the case up to the sight level permits adequate lubrication to a bearing facing forward, but with the engine in the near vertical position the oil in the control is at the opposite end of the case, away from the shaft bearing, and therefore, the bearing is inadequately lubricated. Filling the entire case with oil did not correct the situation because the added oil was forced out of the case by the rotating flyweights. The overspeed control simply limits the engine speeds higher than the setting of a spring tension adjustment by restricting the throttle opening and does not regulate the engine speed. Plate 13 is a photograph of the overspeed governor control.

(e) One magneto misfired during tests. A bench check indicated that one of its coils, firing Nos. 1 and 3 cylinders, had an emf of only 5000 volts, compared to 17,000 volts for the other coil firing Nos. 2 and 4 cylinders. Internal corrosion was also noted in the magneto housing.

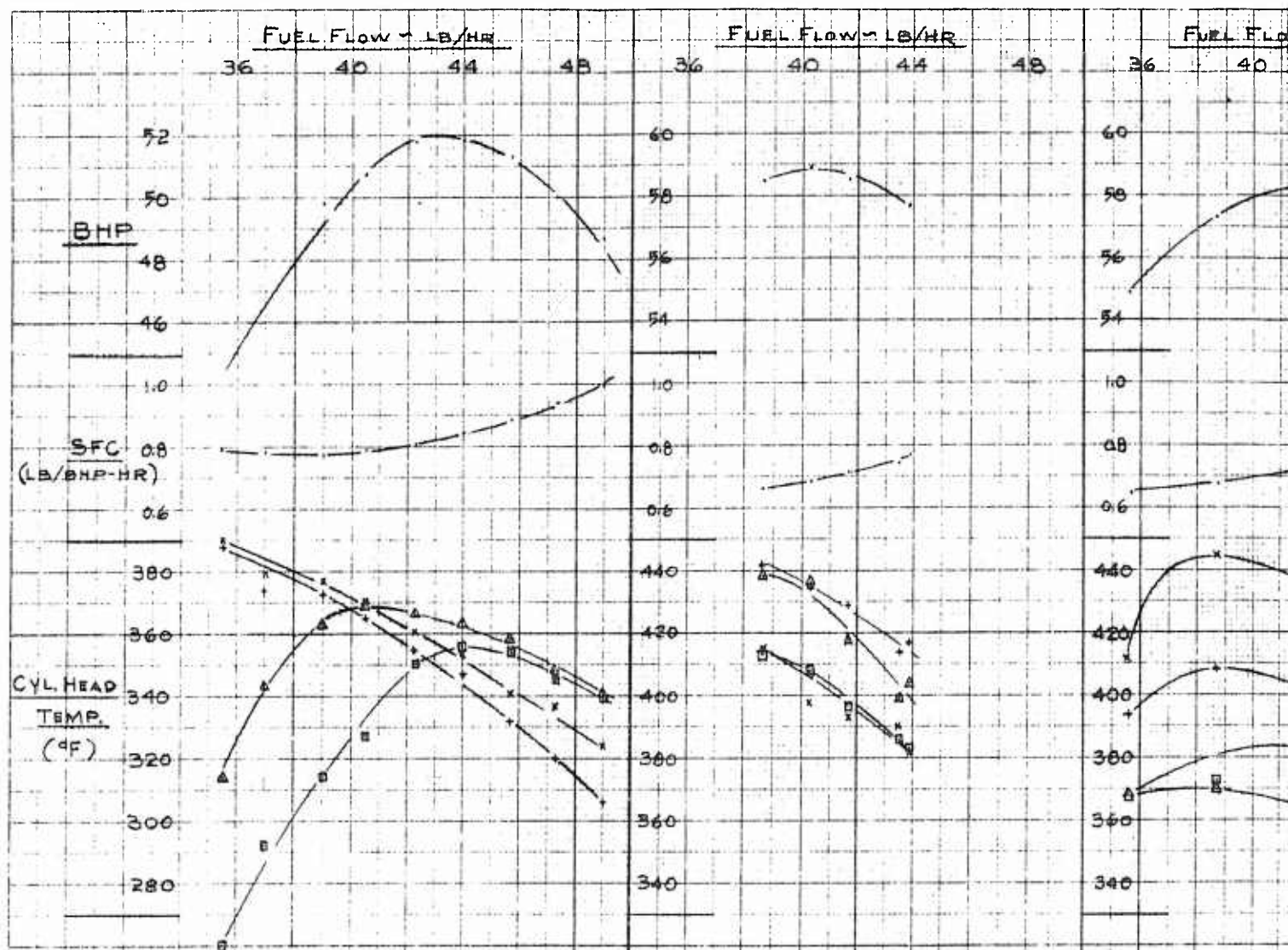
e. Engine Serial No. 431-C-3 (rebuilt) was completely disassembled after the third cylinder retention failure. Visual inspection of the bearings, rods, cylinders, journals, etc. showed them to be in satisfactory condition. A Magnaflux inspection of the steel parts and a Zyglo inspection of the aluminum crankcase showed no incipient failures. Plates 14 and 15 are photographic views of the disassembled engine after the final teardown inspection.

f. Because of the repeated failures, especially those involving cylinder retention, the qualification tests were terminated. The two engines were shipped (see reference b) to the manufacturer for installation of a modified crankcase (see reference d) and other design changes that were deemed necessary. Shortly, thereafter the project was cancelled by reference f.

VIII. REFERENCES

Reference material noted in this report follows:

- a. Project Authorization -- Bureau of Aeronautics letter Aer-PP-2321/128 of 7 Oct 1957
- b. Bureau of Aeronautics speedletter Aer-PP-2322/1 of 23 Jan 1959
- c. Engine Model Specification No. XR-1501 revised 5 Nov 1957-
Navy Model YO-100-4
- d. McCulloch Corporation letter of 7 Nov 1958
- e. Calibration and Qualification Tests of Nelson Model H-59A Engine,
NAMC-AEL-1564 of 23 May 1958
- f. Bureau of Aeronautics letter Aer-PP-15/18 of 6 Mar 1959



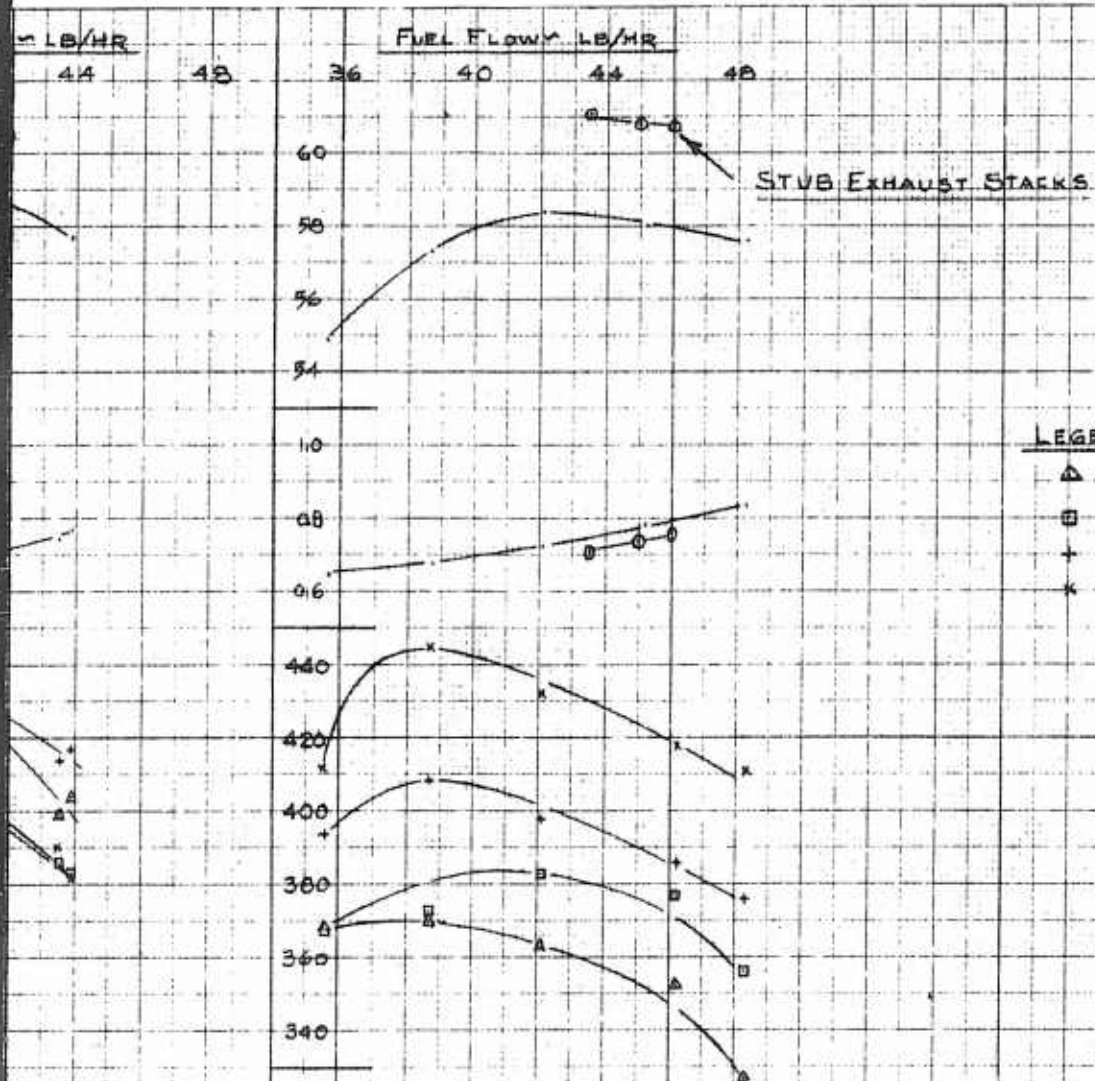
ENGINE SERIAL NO. --- 43-C-1
 THROTTLE POSITION --- FULL THROTTLE
 ENGINE SPEED --- 4000 RPM
 CARB. INT. & EXH. PRESS. --- SEA-LEVEL
 AVG. MANIFOLD PRESS. --- 28.6 IN. Hg
 (MEASURED AT CARB. BASE)

43-C-1
 9° PAST WOT
 4000 RPM
 SEA-LEVEL
 28.3 IN. Hg

NOTE

POWERS CORRECTED TO STANDARD SEA-LEVEL CONDITIONS.
 CYL. HD. TEMPS MEASURED AT SPARK PLUG THERMOCOUPLE,
 OVERSPEED GOVERNOR INSTALLED

1



LEGEND

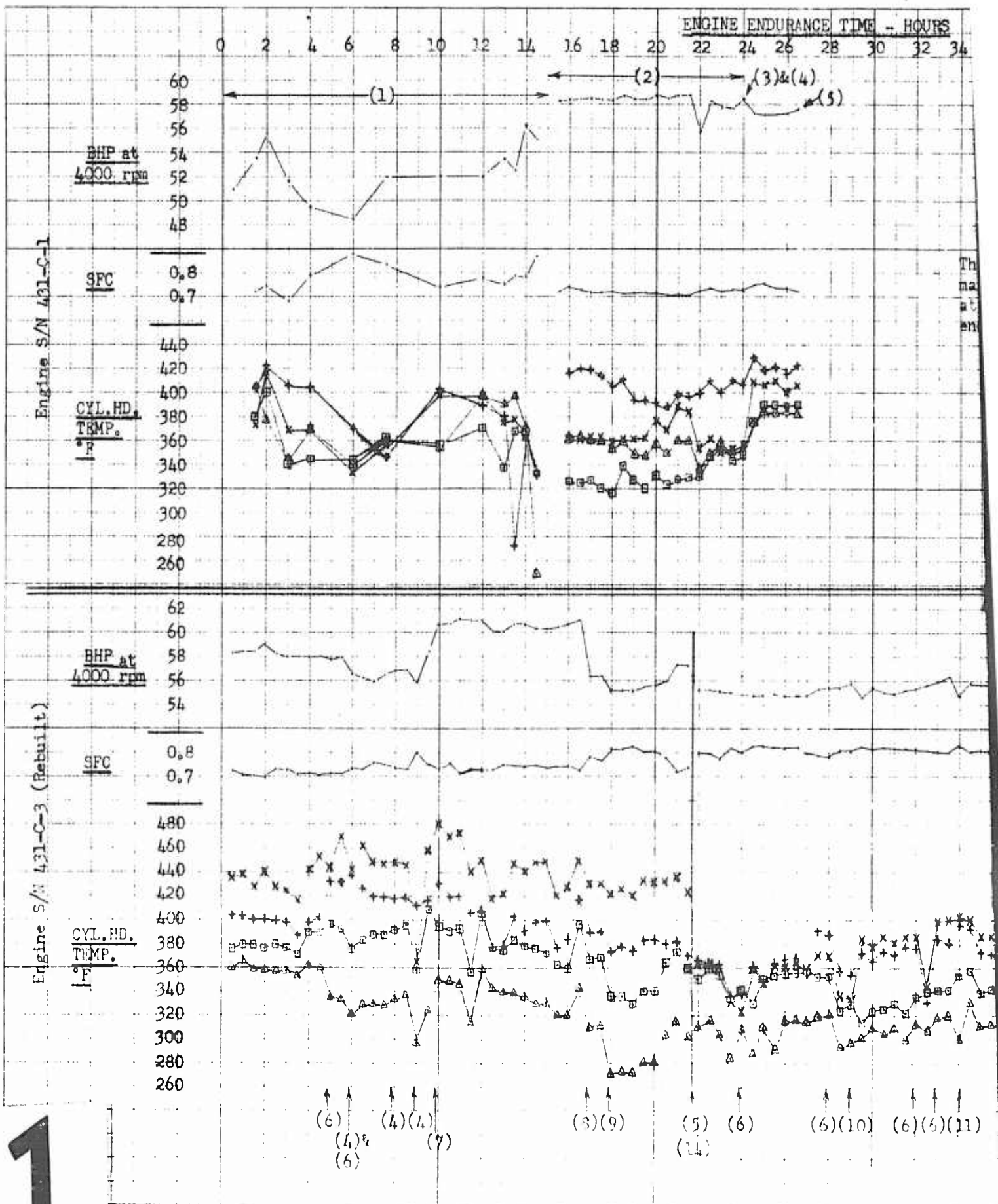
Δ	Δ	NO 1 CYL HO TEMP.
□	□	NO 2 " " "
+	+	NO 3 " " "
x	x	NO 4 " " "

2

431-C-1	431-C-3 (REBUILT)
9° PAST WOT	9° PAST WOT
4000 RPM	4000 RPM
SEA-LEVEL	SEA-LEVEL
28.3 IN. Hg.	27.9 IN. Hg.

DITIONS.
RMOCUPLE,

MIXTURE CONTROL RUNS
MCCULLOCH YD-1000 ENGINE
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER PHILADELPHIA, PA.
Proj. TED No. NAM PP2648, Eng. J. V. SHEARER



ENGINE ENDURANCE TIME - HOURS

22 24 26 28 30 32 34 36 38 40 42 44 46 48 50

(3)&(4)
(5)

NOTE

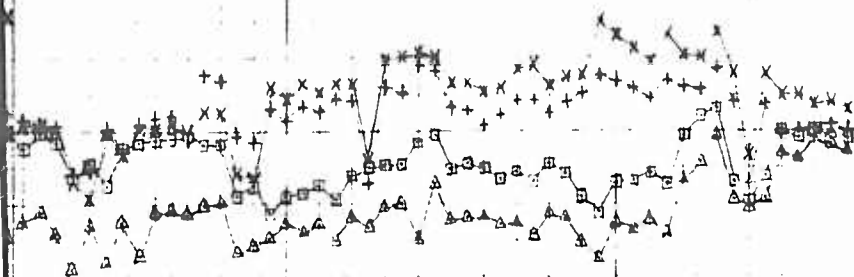
These plotted values were the maximum brake horsepower obtained at each half hour cycle of the endurance runs.

LEGEND

- Δ- No.1 Cylinder Head
- No.2 " "
- + - No.3 " "
- x- No.4 " "

- (1)- 15 hours of miscellaneous tests of engine credited toward endurance time.
- (2)- No Governor overspeed control load.
- (3)- Governor installed on engine.
- (4)- Carburetor throttle and fuel metering adjusted.
- (5)- Engine failure.
- (6)- Exhaust manifold repaired.
- (7)- Stub Stacks installed.
- (8)- Exhaust manifolds installed.
- (9)- Carburetor fuel enriched.
- (10)- Governor overspeed control failure.
- (11)- Spark Plugs cleaned and regapped.
- (12)- Four reconditioned Spark Plugs installed.
- (13)- Replaced Magneto.
- (14)- No. 4 cylinder and piston replaced and the cyclic test continued.

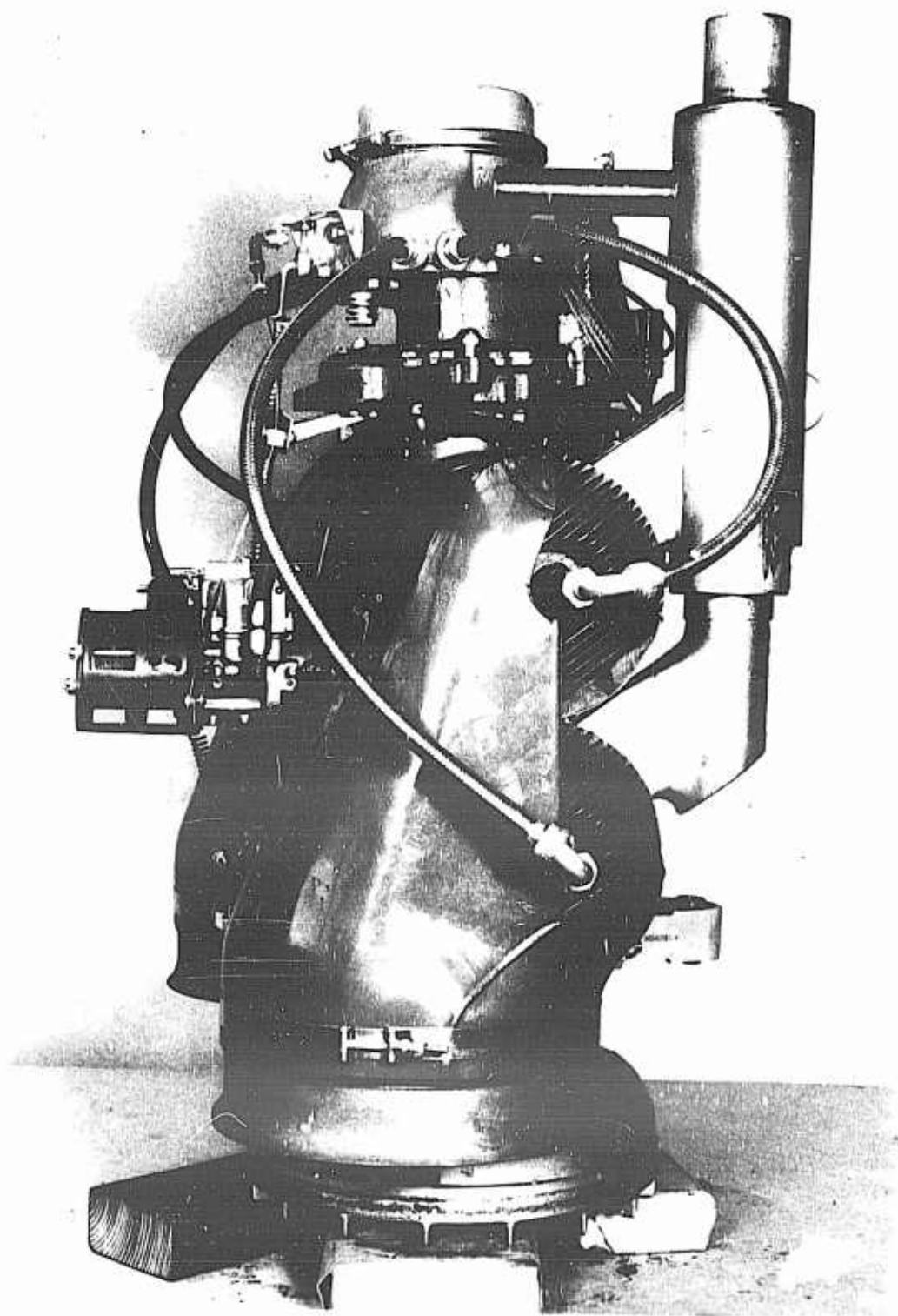
2



(5) (6) (6)(10) (6)(5)(11) (7) (13)(1) (5) (12)

ENDURANCE TIME
1/2 CULLOCH VC-100-4 ENGINE
S/A 431-G-2 & 431-G-3 (Rebuilt)
AERONAUTICAL ENGINE LABORATORY
NAVAL AIR MATERIAL CENTER, PHILADELPHIA, PA.
Proj. TED No. NAM PP-2548-1 Engr. C.W. SHEARER

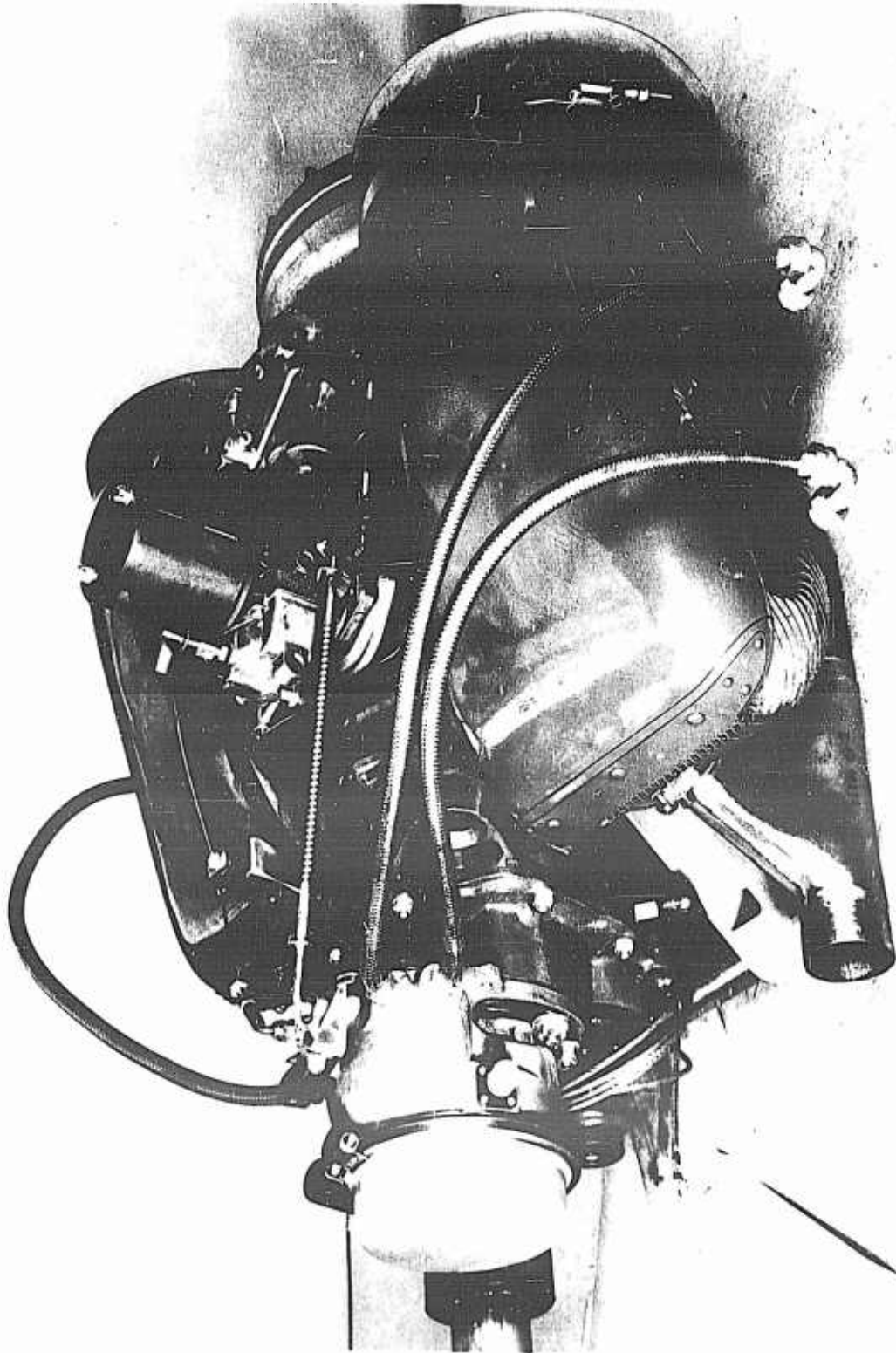
PLATE 2



SIDE VIEW OF YO-100-4 ENGINE

PHOTO NO: CAN-307936(L)-2-58

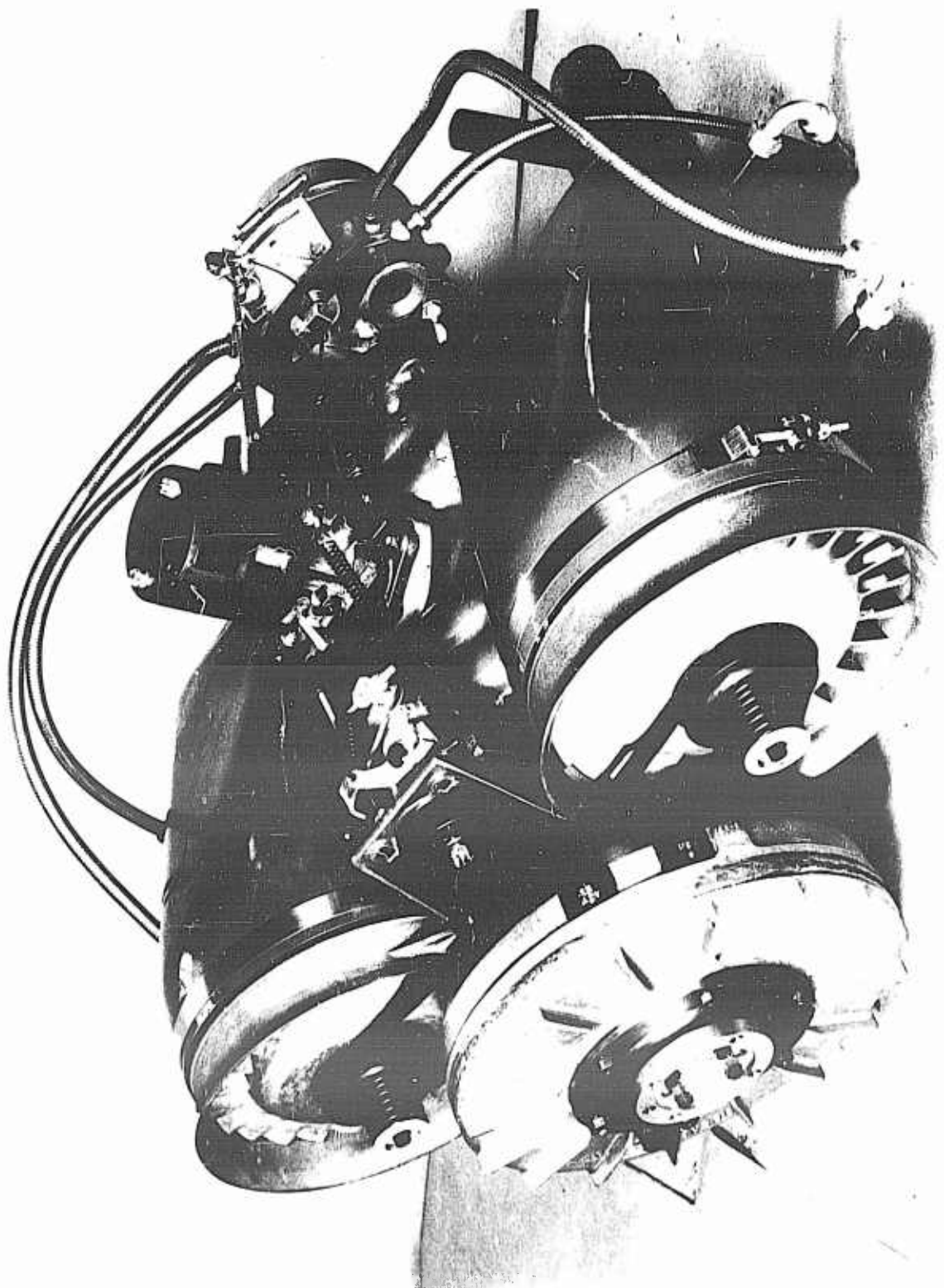
PLATE 3



YO-100-4 ENGINE
REAR SIDE VIEW

PHOTO NO: CAN-307940(L)-2-58

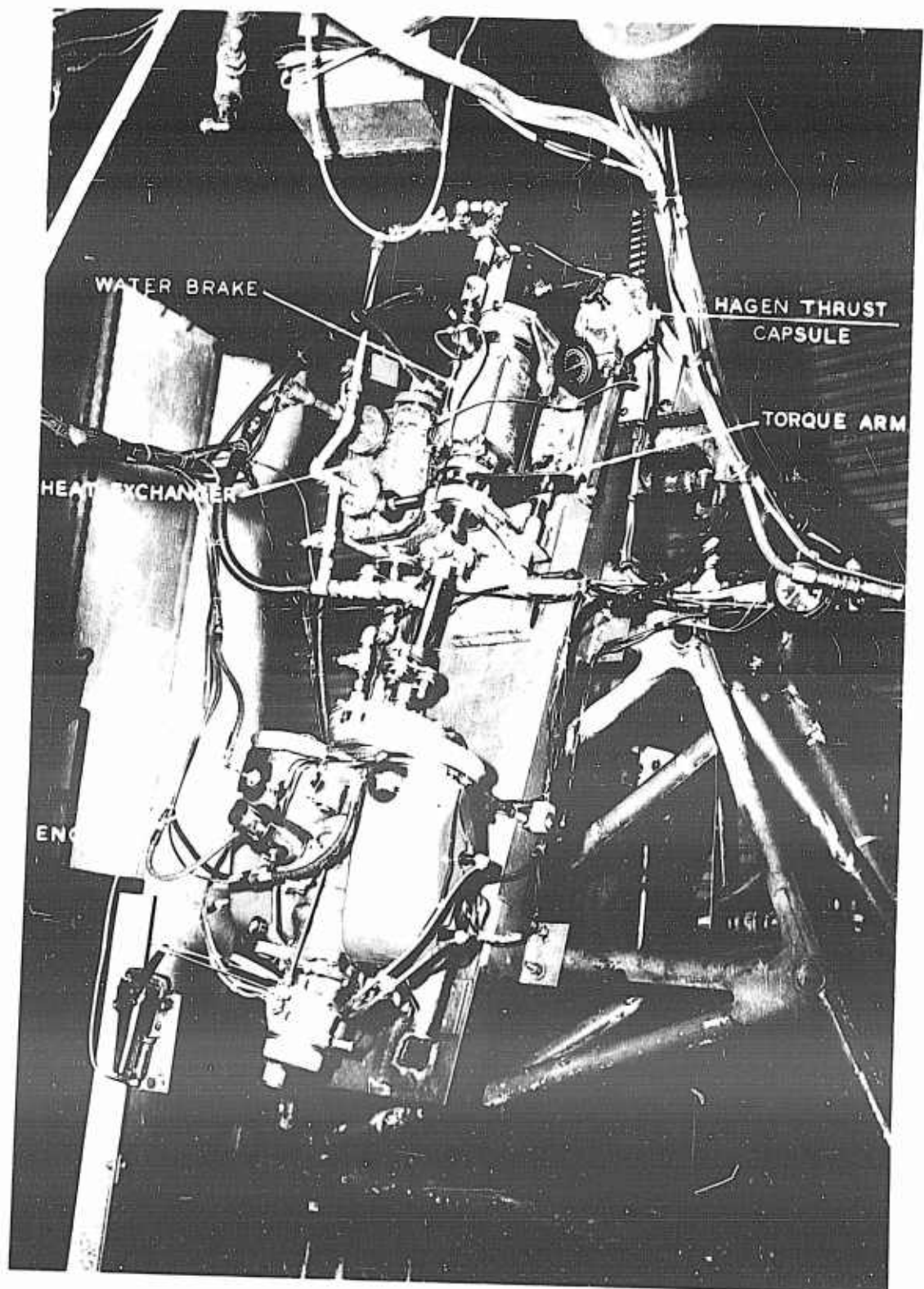
PLATE 4



McCULLOCH YO-100-4 ENGINE
SHOWING FLUID COUPLING AND COOLING FANS

PHOTO NO: CAN-307941(L)-2-58

PLATE 5



TEST CELL INSTALLATION (15° from Vertical) OF McCULLOCH YO-100-4 ENGINE

PHOTO NO: CAN-308429(L)-3-58

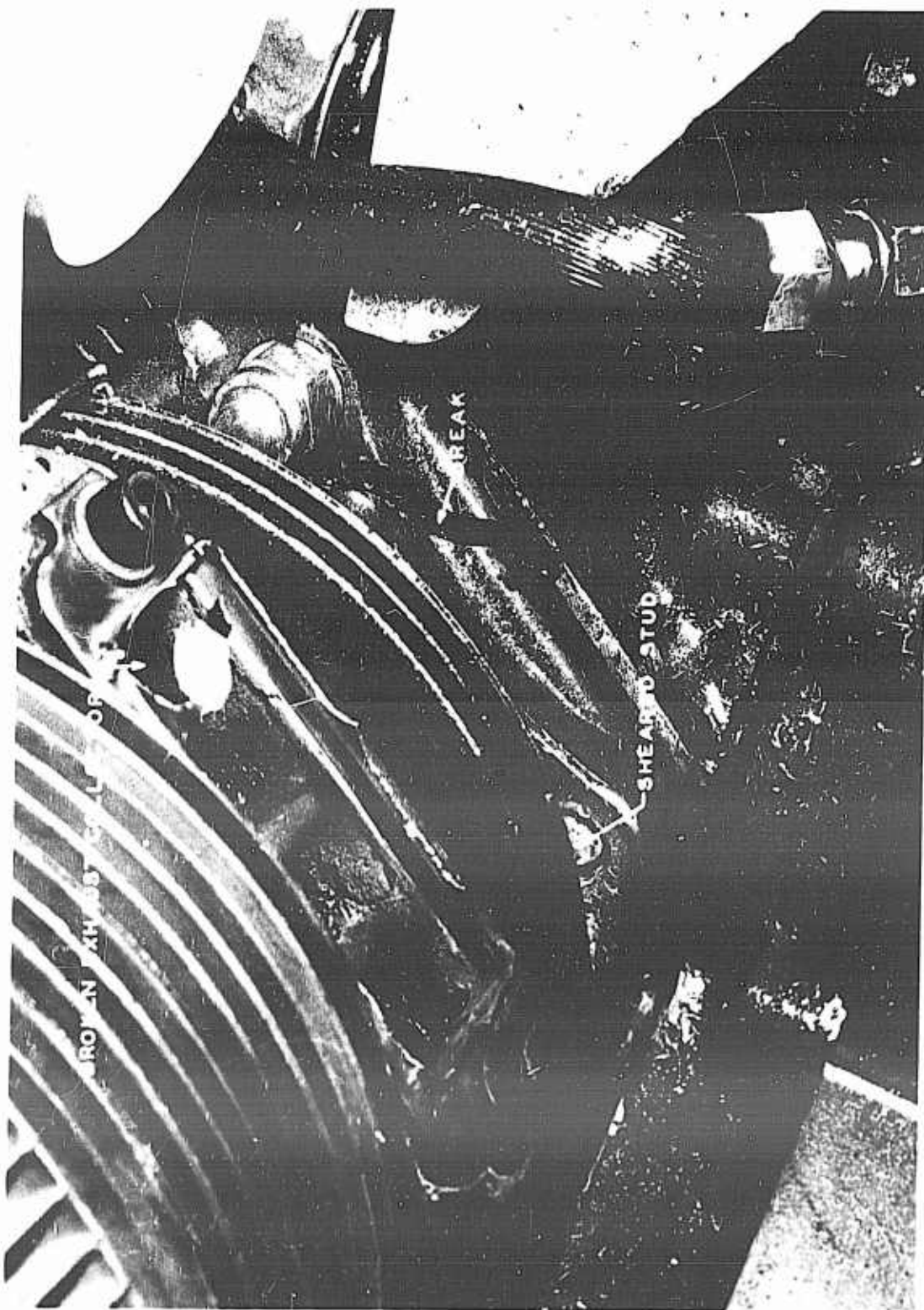
PLATE 6



TEST CELL FOOT TREADLE STARTING DEVICE

PHOTO NO: CAN-308937(L)-3-58

PLATE 7



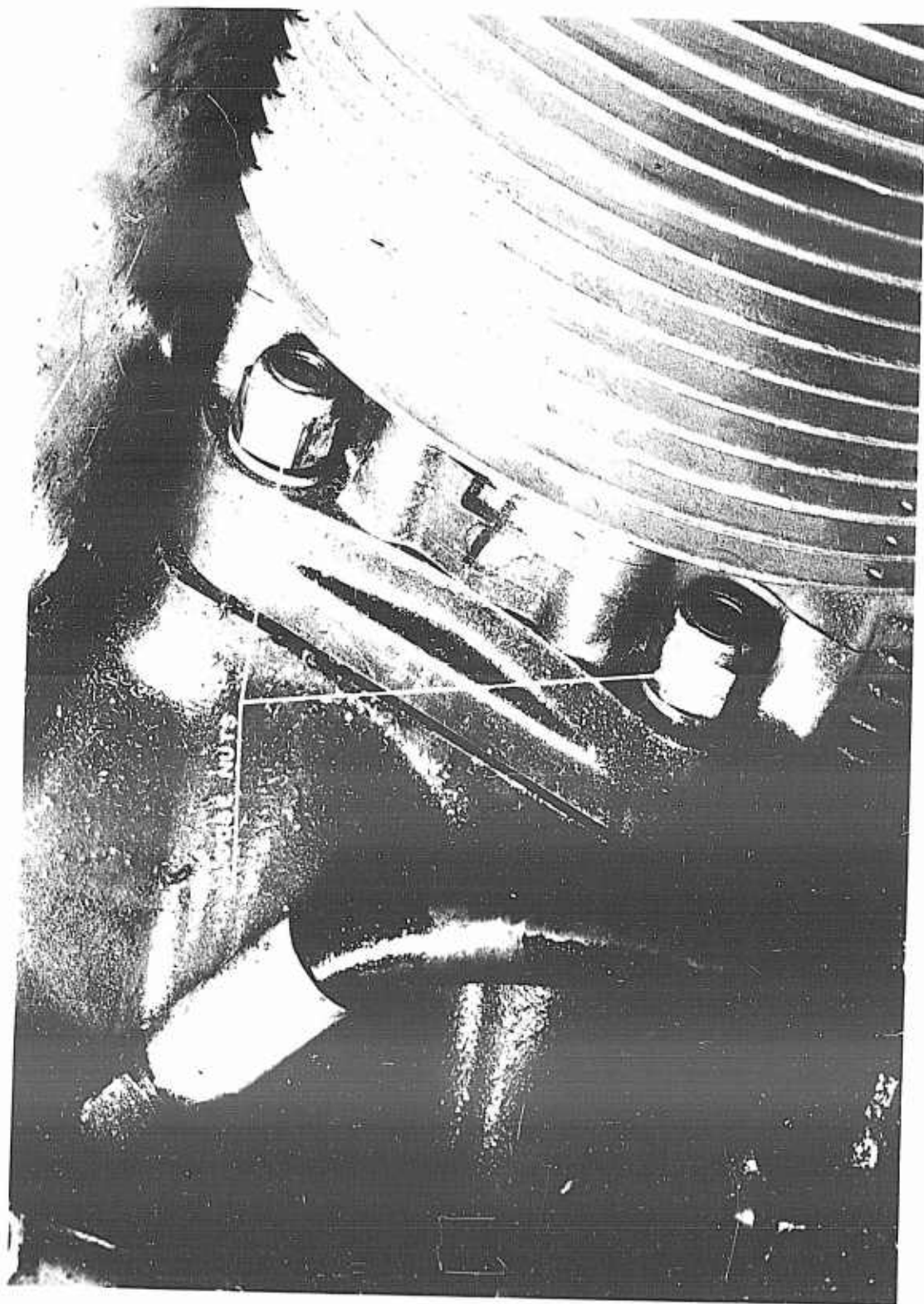
SECOND FAILURE OF NO. 4 CYLINDER RETENTION

ENGINE S/N 431-C-3 (REBUILT)

21.5 HOURS ENDURANCE TIME

PHOTO NO: CAN-314932(L)-12-58

PLATE 8



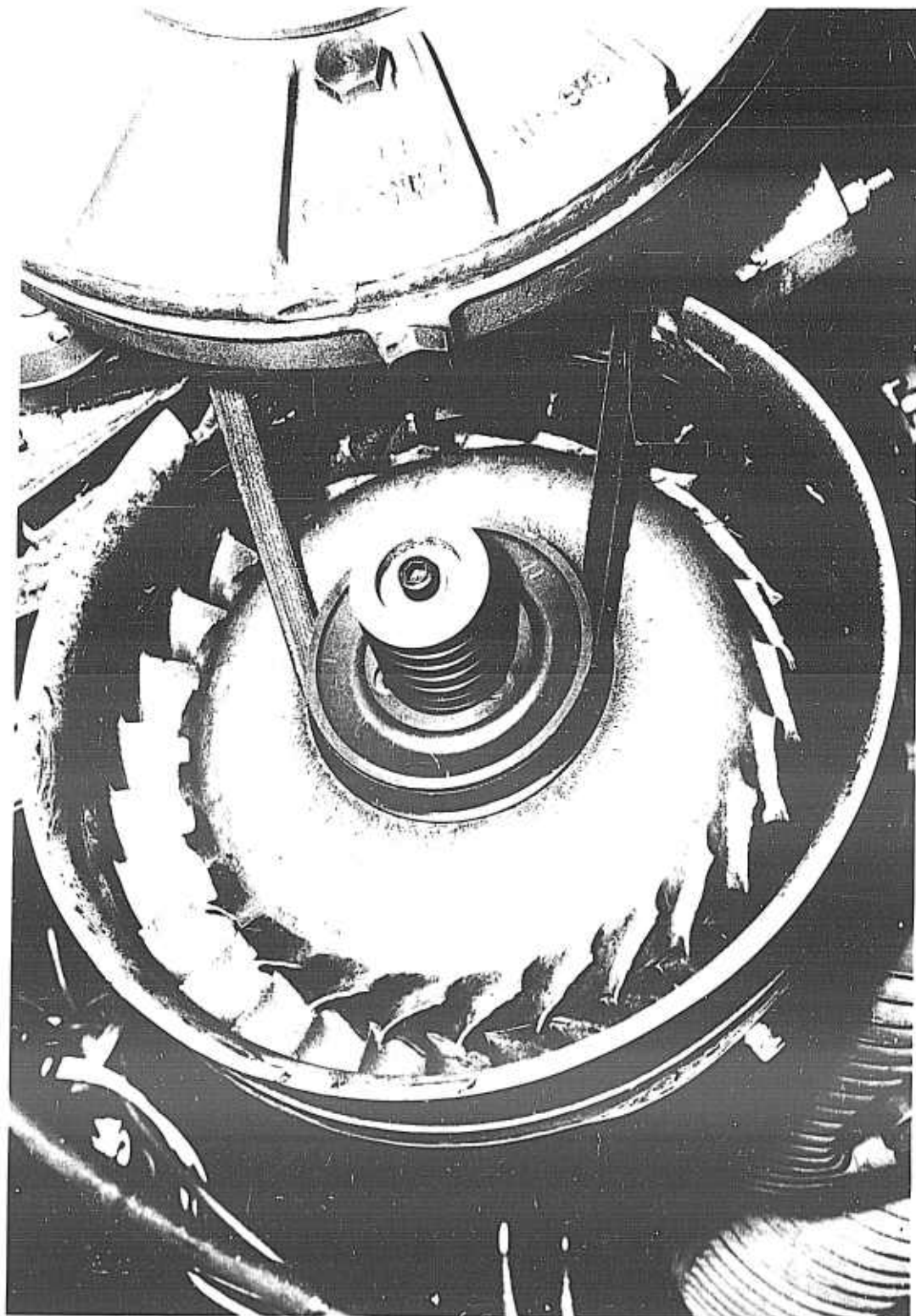
SECOND FAILURE OF NO. 4 CYLINDER RETENTION

21.5 HOURS ENDURANCE (28.3 HRS. TOTAL) - ENGINE S/N 431-C-3 (REBUILT)

LOOSE CYL. HOLD DOWN NUTS

PHOTO NO: CAN-314933(L)-12-58

PLATE 9

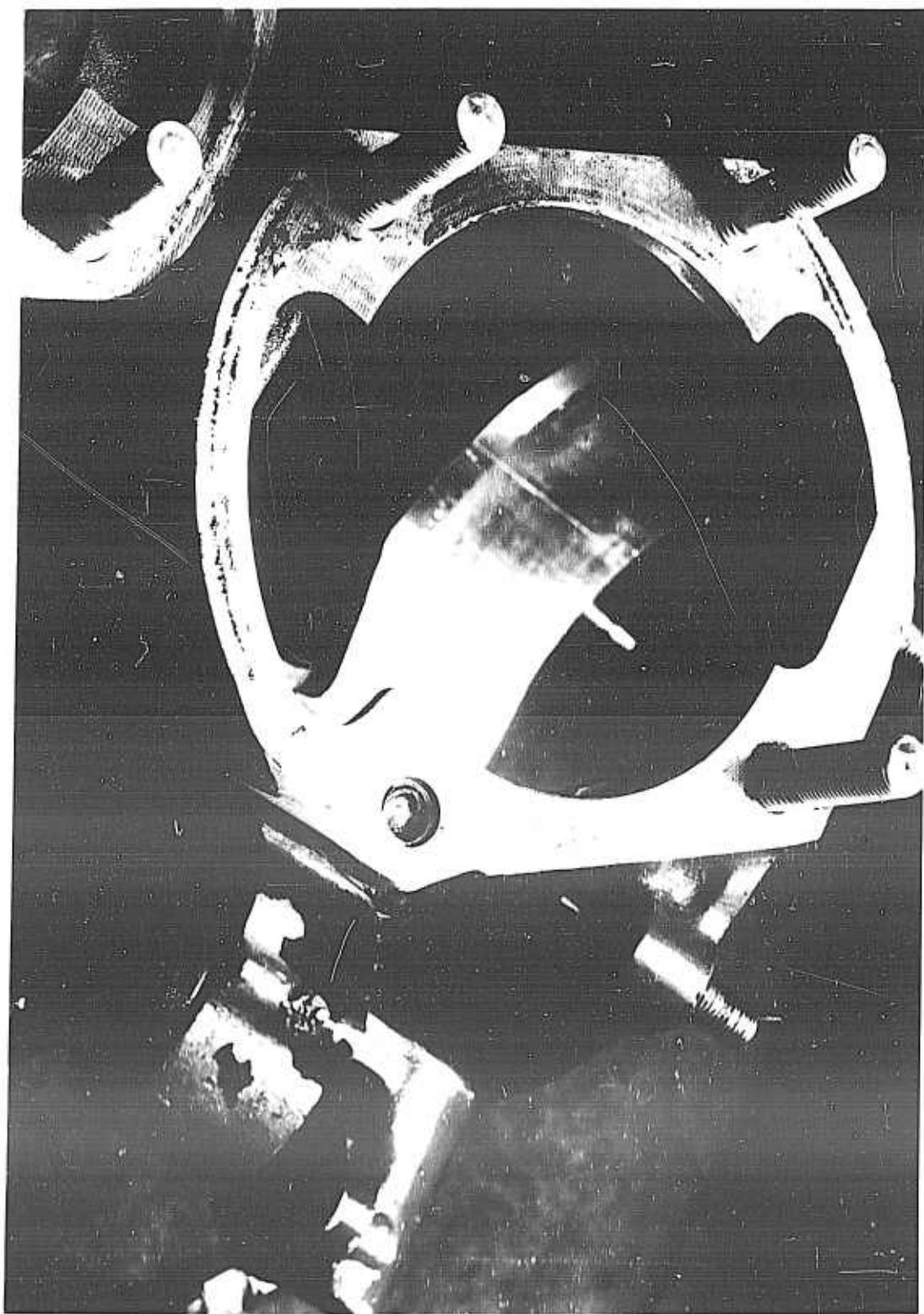


FAILURE OF R.H. COOLING FAN

21.5 HOURS ENDURANCE (28.3 HRS. TOTAL) - ENGINE S/N 431-C-3 (REBUILT)
(Secondary to Cylinder Failure)

PHOTO NO: CAN-314931(L)-12-58

PLATE 10

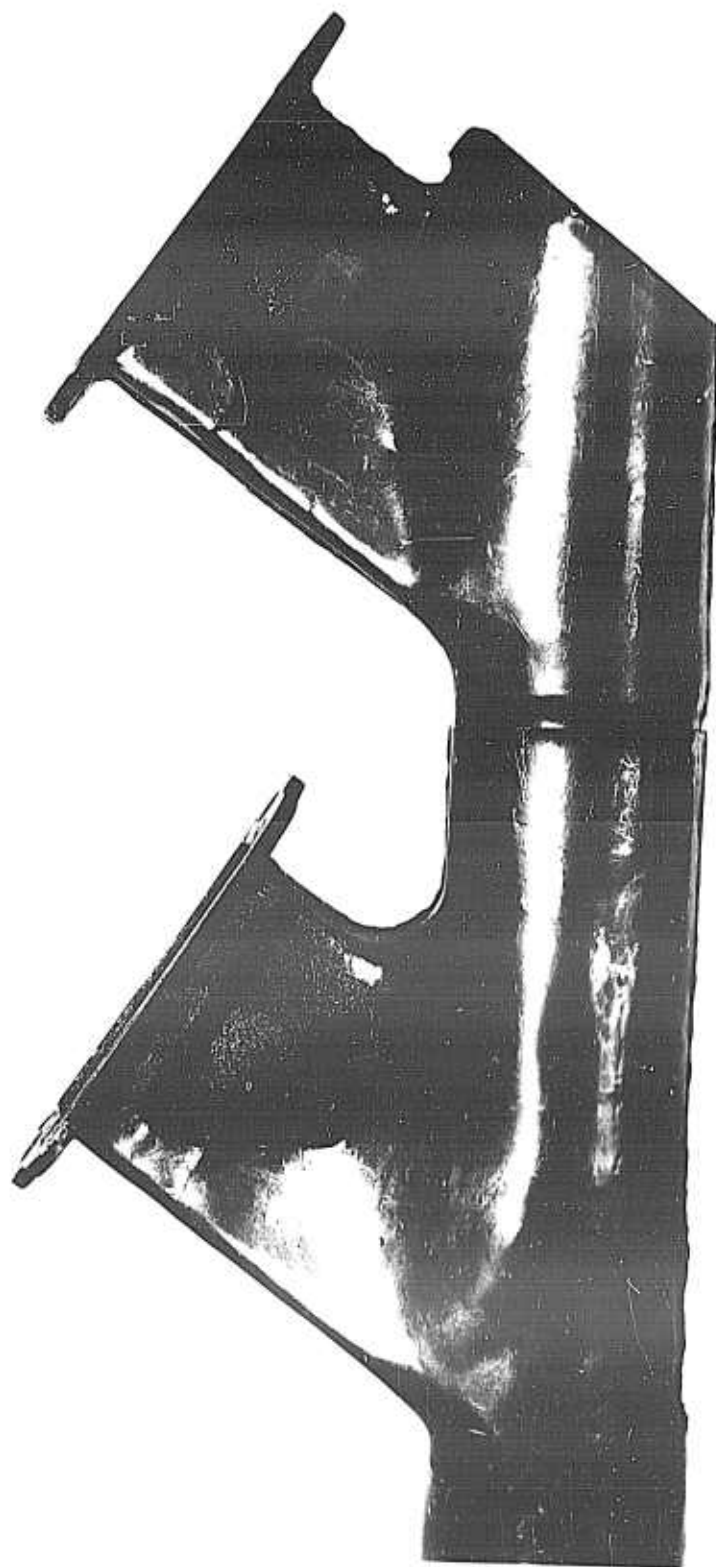


THIRD FAILURE OF NO. 4 CYLINDER RETENTION

25.5 HOURS ADDITIONAL ENDURANCE TIME - ENGINE S/N 431-C-3 (REBUILT)

PHOTO NO: CAN-315873(L)-1-59

PLATE 11



TYPICAL FAILURE OF EXHAUST COLLECTOR MANIFOLD

PHOTO NO: CAN-314598(L)-11-58

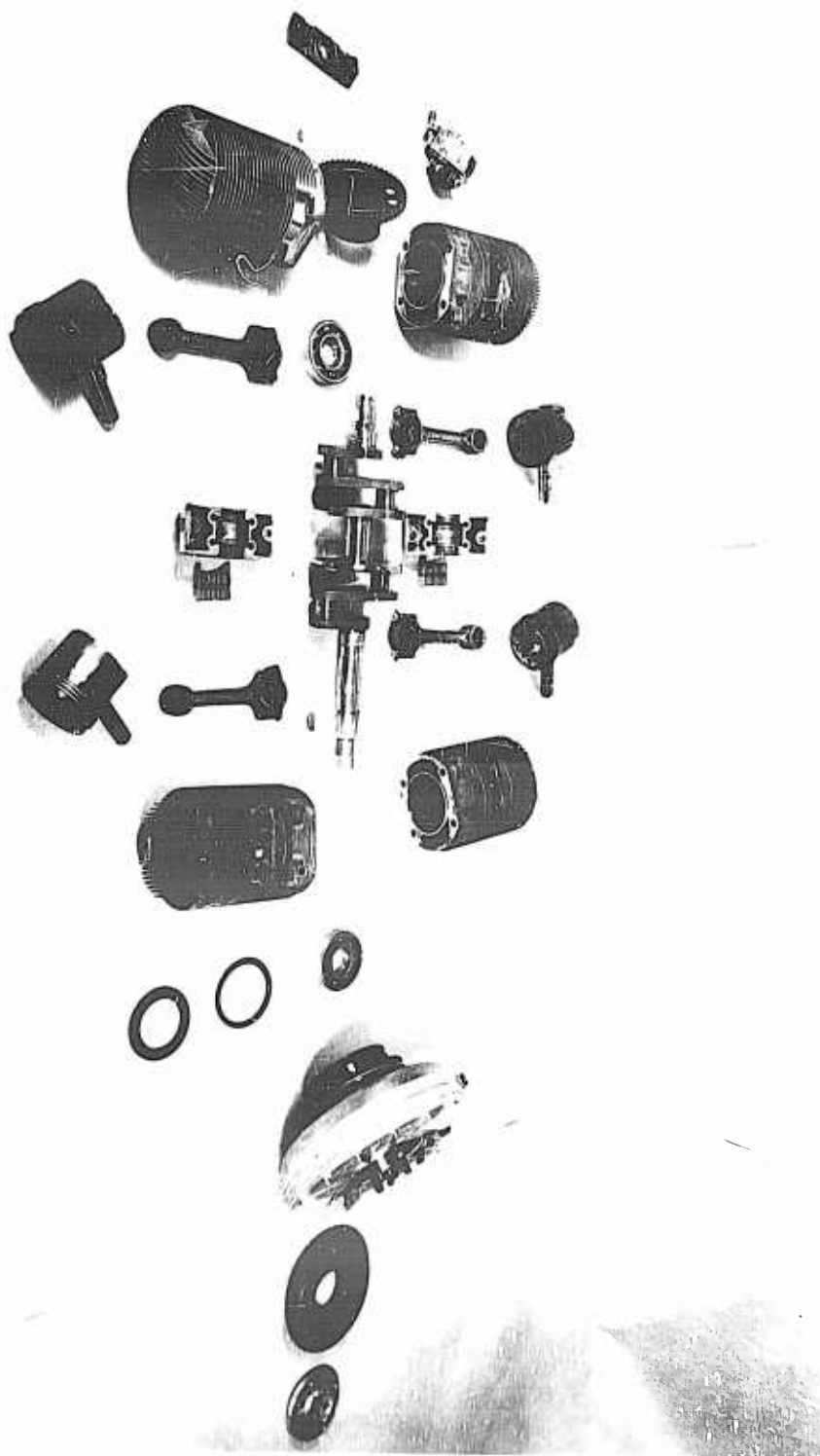
PLATE 12



VIEW OF OVERSPEED GOVERNOR CONTROL

PHOTO NO: CAN-313917(L)-10-58

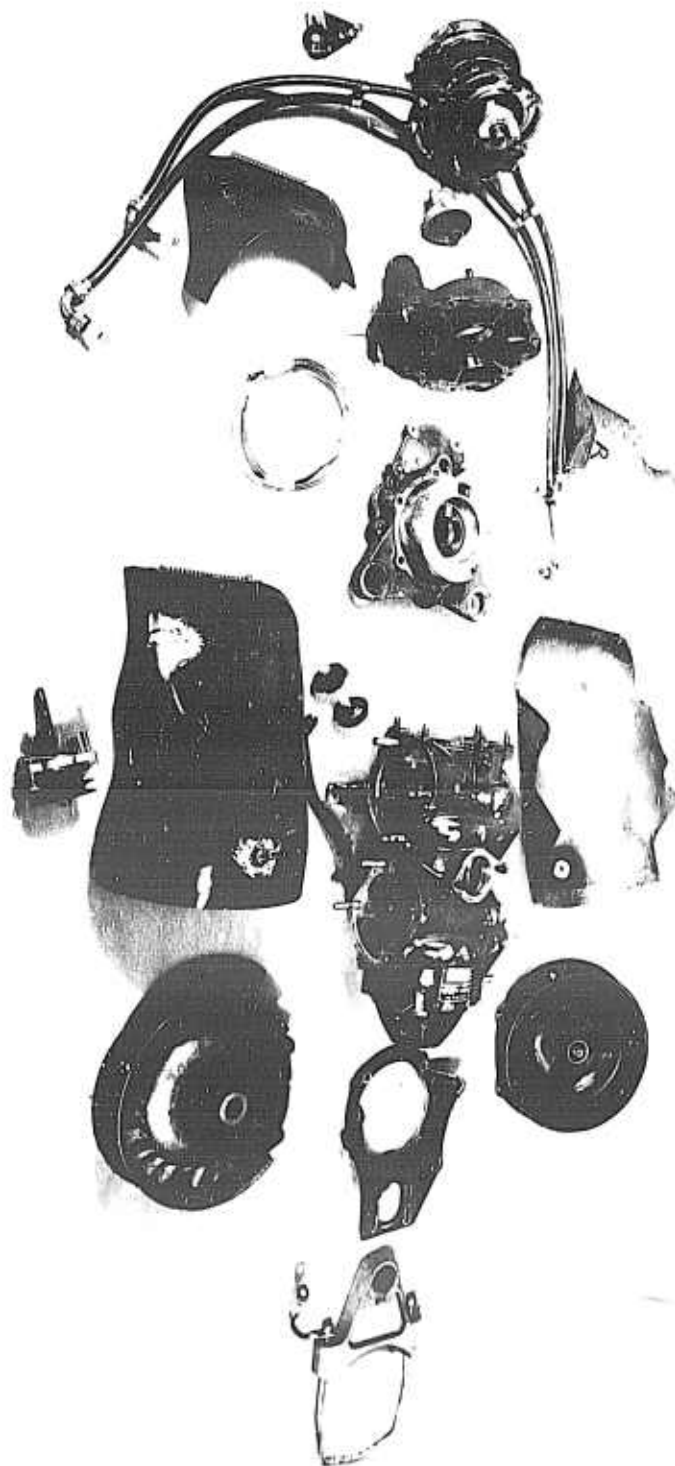
PLATE 13



McCULLOCH YO-100-4 ENGINE, EXPLODED VIEW OF POWER SECTION COMPONENTS

PHOTO NO: CAN-315874(L)-1-59

PLATE 14



MCCULLOCH YO-100-4 ENGINE, EXPLODED VIEW OF COMPONENTS

PHOTO NO: CAN-315875(L)-1-59

PLATE 15

APPENDIX 1

A1-1

REPORT OF TEST 4ND-GEN-2238		REPORT NO. AML 36012-58
FROM Director, AML	TO Director, AEL	PAGE 1 OF 2 PAGES
REQUESTED BY C. W. Shearer		DATE 6 AUG 1958
TEST OF Metallurgical Examination of Engine Crankshaft - McCulloch		PROJECT NO. PP 2648.1
O-100-4 Engine		JOB ORDER NO. 52811
SUPPLIER	QUANTITY REPRESENTED	SCHEDULE NO.
CONTRACT	REQUISITION NO.	RECEIVING NO.

Ref: (a) ILWR AEL No. 11-58 of 14 May 1958

- Encl: (1) Photograph of Crankshaft Assembly of McCulloch O-100-4 Engine
 (2) Photograph (Approximately 2X) of Failed Area, Showing Woodward Keyway
 (3) Photograph (Approximately 2X) of Failed Area Rotated 90° to Right of View Given in Enclosure (2)
 (4) Photograph (Approximately 2X) of Failed Area Rotated 180° From View Given in Enclosure (2)
 (5) Photograph (Approximately 2X) of Failed Area Rotated 270° to Right of View Given in Enclosure (2)
 (6) Photograph of Fracture Face (Section Removed from B to Show Face)
 (7) Photomicrograph (Approximately 5X) of the Fracture Face Seen on Part B shown in Enclosure (2)

1. Reference (a) forwarded a failed crankshaft taken from a McCulloch O-100-4 engine for metallurgical examination to determine the nature and cause of failure.

2. Visual examination of the cross-section of the crankshaft in the failed area revealed that the main fracture followed a path indicative of torsional shear. The incipient cracks at the corners of the Woodruff Key way opposite to the corner of the main fracture confirmed this observation as did the path of the failure about the circumferential cross-section of the crankshaft. Enclosure (1) shows the locale of the failure in reference to the crankshaft assembly. Enclosures (2), (3), (4) and (5) show a close up view of the path of fracture. Enclosures (4) and (5) reveal the galling which occurred at the crankshaft - fluid coupling assembly interface. On opening the fracture, the typical "oyster shell" markings indicative of the action of a fatigue mechanism were revealed. These marks indicated that the failure originated at the sharp corner between the lateral side and curve base of the Woodruff Keyway located approximately between the crankshaft surface and the base of the keyway. The lack of concentricity of the lightening hole in this portion of the crankshaft made the material cross-sectional thickness at the base of the keyway quite thin. Numerous tool marks were observed on the surface of the lightening hole.

APPROVED E. S. Williams By Direction	APPROVED W. J. Felgus, Head Physical Metallurgy Branch	REPORTED BY H. A. Sipes Test Engineer
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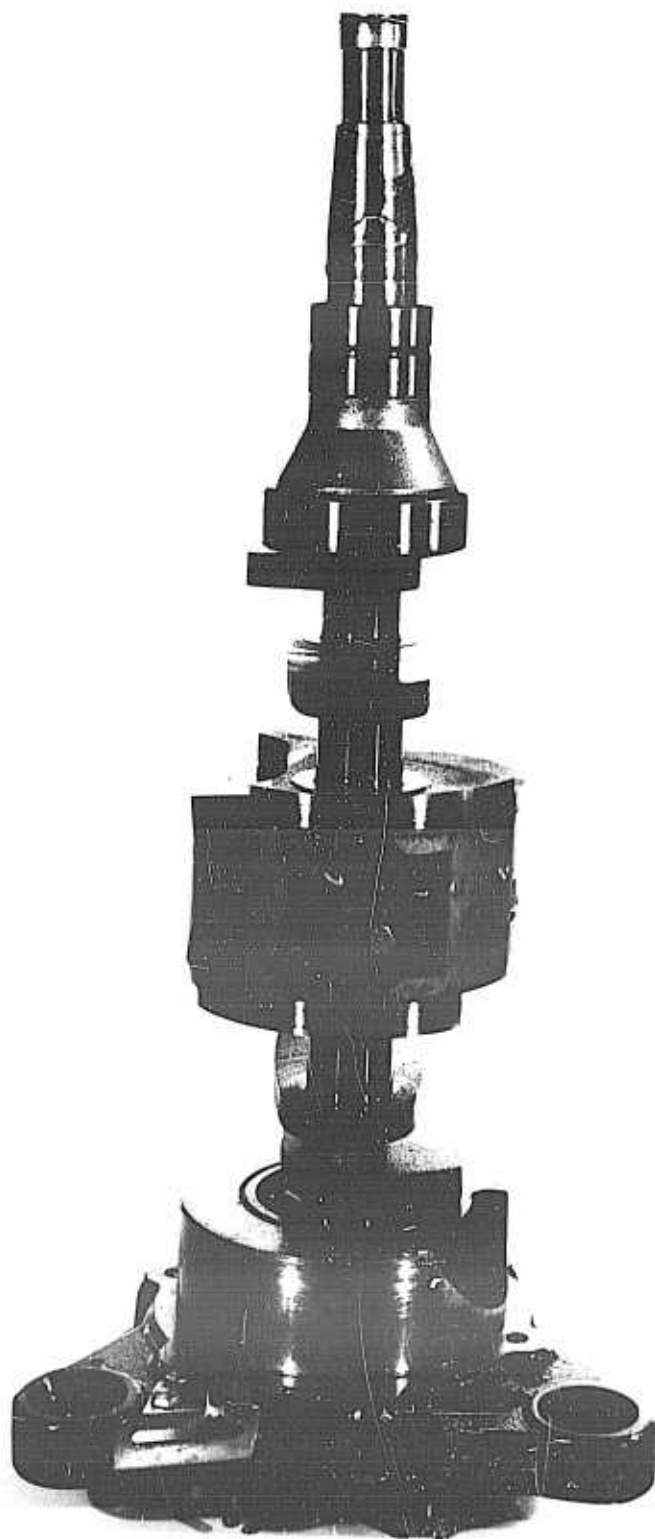
NAVY-OPPO 4ND-PHILA., PA.

3. Microscopic examination of the crankshaft material showed it to be clean, sound, and free from internal defects. The microstructure was typical of material that had been heat treated to the normalized condition, as required by the specification of the manufacturer's drawing. The hardness of the crankshaft was determined to be R_c-26 , within the range of $R_c 24-34$ as specified by the drawing. Chromium plating as specified by the same drawing for this area was observed but not measured for plating thickness.

4. From the foregoing examination, it is concluded that the failure occurred by the fatigue mechanism. This was initiated by the cyclic stresses concentrated in the sharp corner in the Woodruff keyway (described in Section 2 above and shown in enclosure (6)). The galled surfaces shown in enclosures (4) and (5) are indicative of poor bearing contact between the crankshaft and hydraulic coupling. In view of the detailed instructions found in the manufacturer's drawing #263253 with regard to the elimination of tool marks in the lightening hole and the emphasized details concerning the tolerance limits for fillet radii exclusive of the keyway, the sharp edges and contours found in the Woodruff keyway would seem to indicate a design oversight or possible poor fabrication practice. Whether or not design, fabrication, or assembly was deficient with regard to this engine is beyond the purview of this report. There is insufficient data available for determining the origin of the cyclic torsional stresses which produced the fatigue failure. However, since the metallurgical examination gave no evidence that the failure was due to a material deficiency, it is suggested that the vibrational effects of crankshaft rotation, as evidenced by the galling and the working stresses imposed by the operative stresses, added to the notch effect of the Woodruff keyway, triggered the failure.

5. It is, therefore, recommended that the design, fabrication, and assembly of the engine and its components be reviewed with regard to the elimination of notch effects, proper bearing contacts, and misalignment.

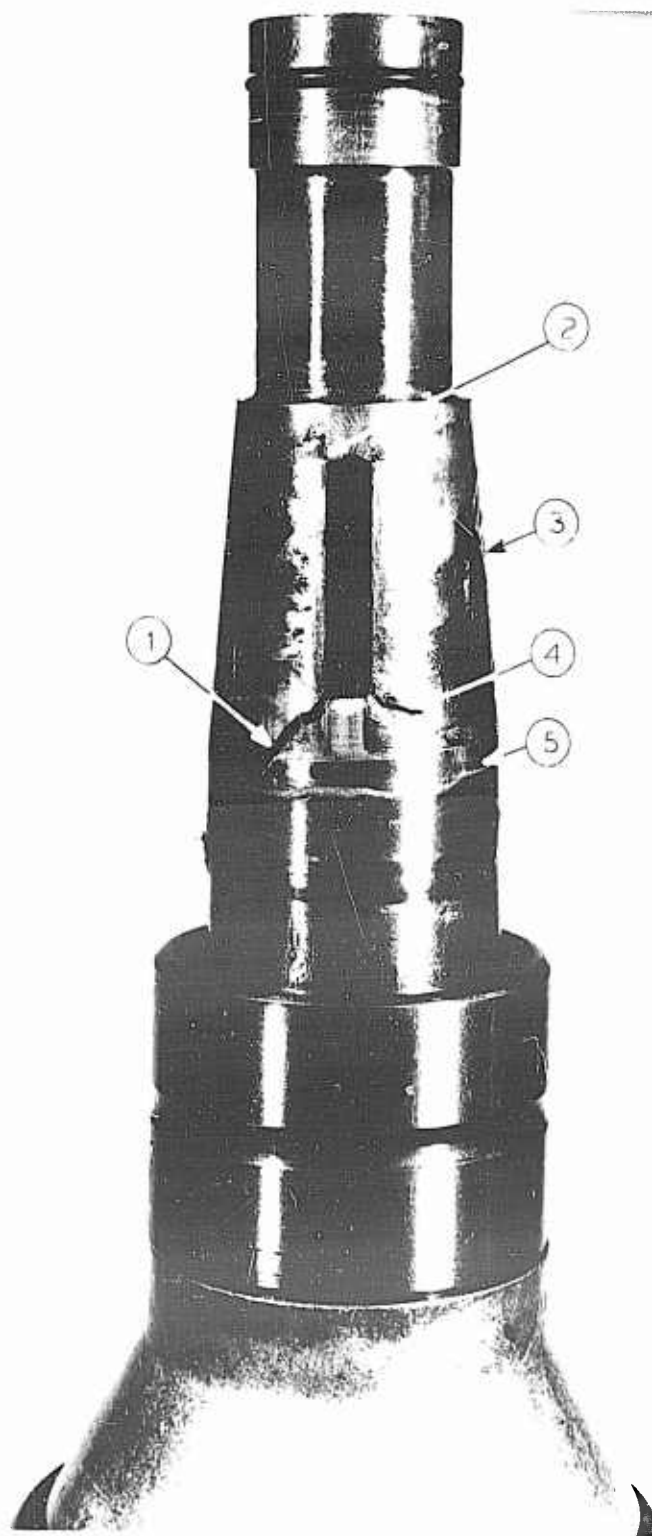
6. This completes the work requested by reference (a) above.



CRANKSHAFT ASSEMBLY OF McCULLOCH 0-100-4 ENGINE

PHOTO NO: CAN-310127(L)-5-58

ENCLOSURE (1)

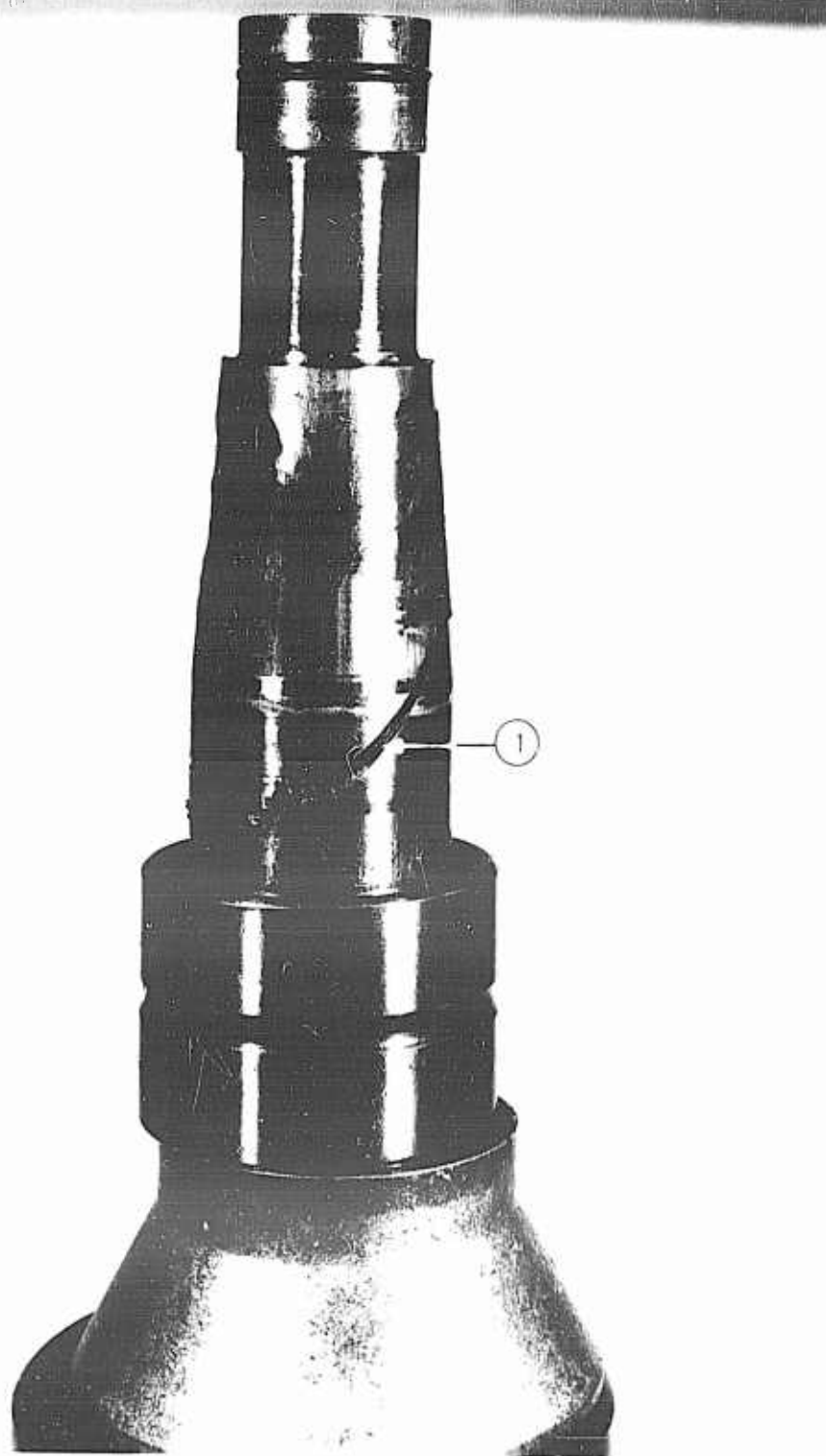


- | | | |
|-------------------------|---------------------|----------------------|
| 1. Main path of failure | 2. Incipient cracks | 4. Secondary failure |
| angular path indicates | 3. Galled surface | 5. End of main path |
| torsion effects | | of failure |

FAILED AREA OF CRANKSHAFT SHOWING WOODRUFF KEY

PHOTO NO: CAN-310129(L)-5-58

ENCLOSURE (2)

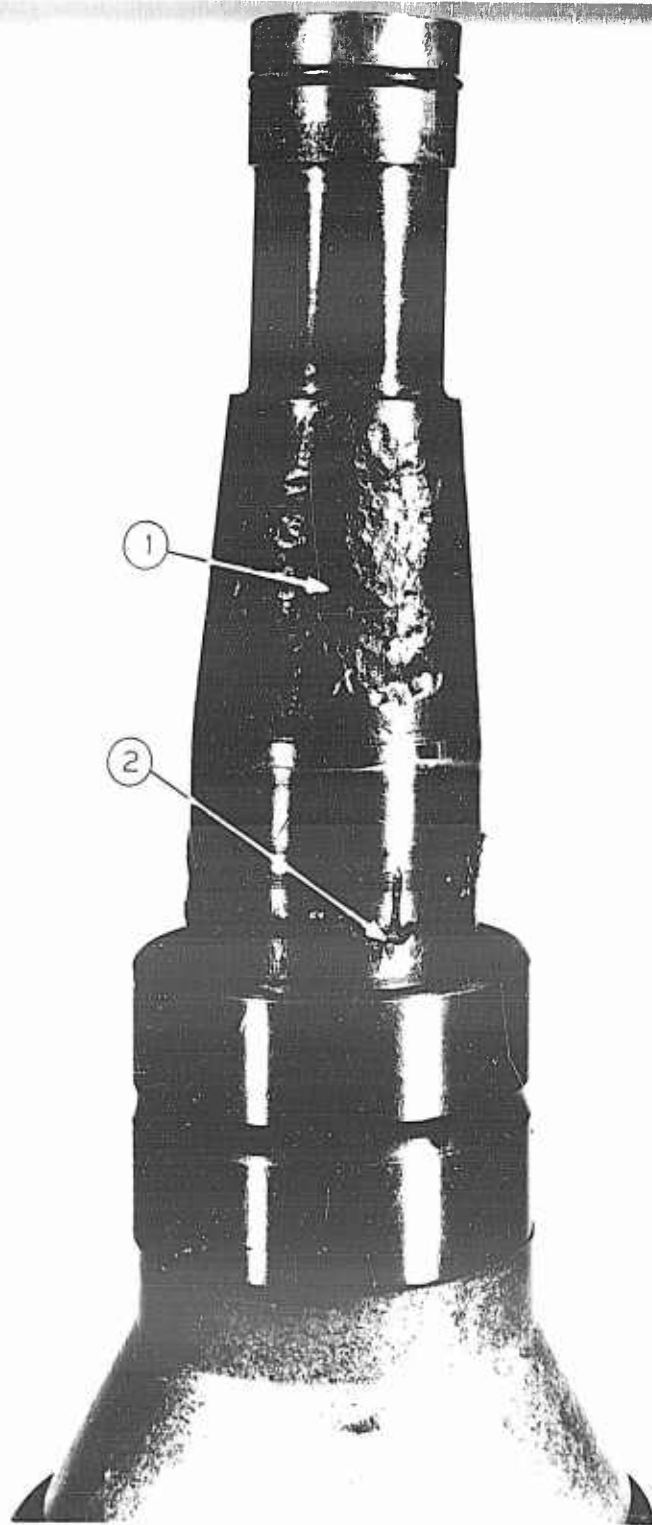


1. Main path of failure - angle of path indicates torsional effects

FAILED AREA OF CRANKSHAFT, ROTATED 90° TO RIGHT OF VIEW GIVEN IN ENCLOSURE (2)

PHOTO NO: CAN-310126(L)-5-58

ENCLOSURE (3)



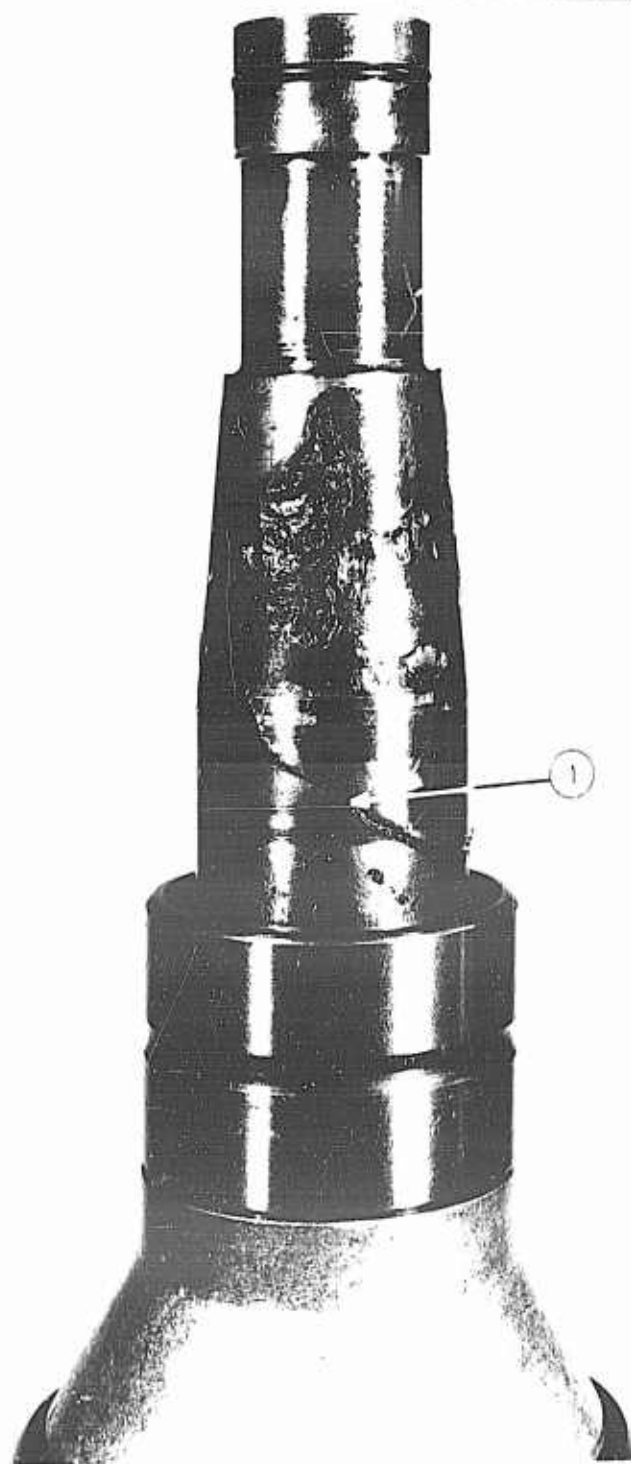
1. Galled Area

2. Path of Failure

FAILED AREA OF CRANKSHAFT, ROTATED 180° TO THE VIEW GIVEN IN ENCLOSURE (2)

PHOTO NO: CAN-310130(L)-5-58

ENCLOSURE (4)

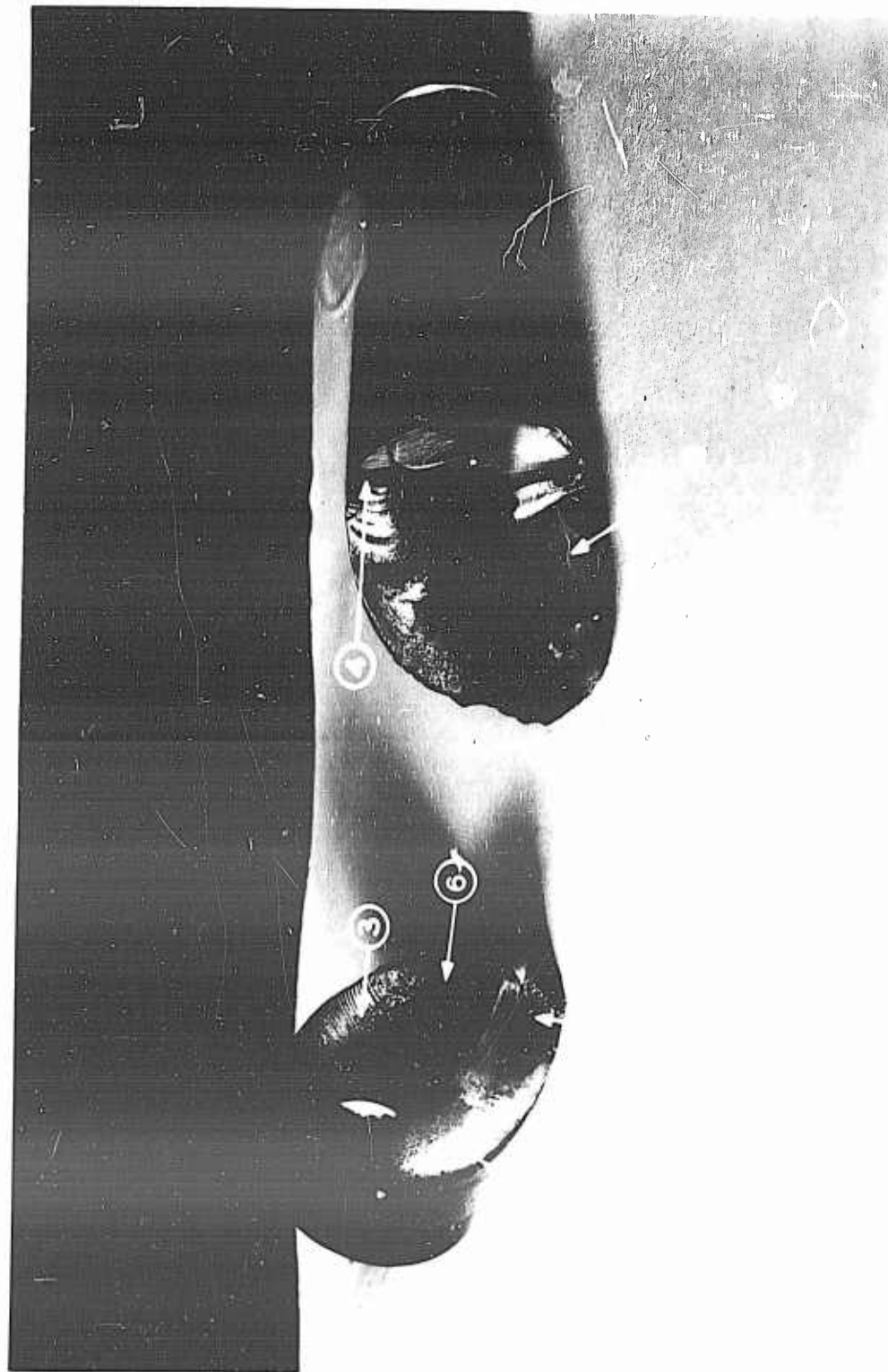


1. Path of failure

FAILED AREA OF CRANKSHAFT, ROTATED 270°
TO RIGHT OF VIEW GIVEN IN ENCLOSURE (2)

PHOTO NO: CAN-310128(L)-5-58

ENCLOSURE (5)



- | | |
|--------------------------|---|
| 1. Rubbed surface | 4. Origin of failure |
| 2. Oyster shell markings | 5. Section removed for viewing |
| 3. Final fatigue | 6. Broken through when opening fracture faces |

FRACTURE FACES: A rotated 180° may be mated to B.

PHOTO NO: CAN-311954(L)-7-58

ENCLOSURE (6)



1. Origin of failure

FRACTURE FACE OF B SHOWING ORIGIN OF FAILURE - Fracture Face in Plane of View

PHOTO NO: CAN-311953(L)-7-58

ENCLOSURE (7)

APPENDIX 2

A2-1

REPORT OF TEST 4ND-GEN-2238		REPORT NO. AML 36004-59
FROM Director, AML	TO Director, AEL	PAGE 1 OF 2 PAGES
REQUESTED BY C. W. Shearer		DATE 28 JAN 1959
TEST OF Metallurgical Investigation of Failed McCulloch YO-100-4 Engine		PROJECT NO. PP 2648.1
SUPPLIER	QUANTITY REPRESENTED	JOB ORDER NO. 52811
CONTRACT	REQUISITION NO.	SCHEDULE NO.
		RECEIVING NO.

Ref: (a) AEL Work Request 7-59 of 10 Oct 1958

- Encl: (1) General View of Fractured Engine Case
 (2) General View of Fractured Cylinder
 (3) Fracture Face at Cylinder Stud Hole
 (4) Fracture Face at Flange Stud Hole
 (5) Porosity in Fracture Face
 (6) Fracture Face of Stud No. 1
 (7) Crack in Stud Thread Root
 (8) Microstructure of Engine Case; Shrinkage Cavity

1. Reference (a) forwarded the failed components of a McCulloch YO-100-4 engine for metallurgical examination to determine the probable cause of failure.

2. Visual examination revealed that failure occurred in the No. 4 cylinder. Further examination disclosed that the stud labeled No. 1 (enclosure (1)) had failed just below the top portion of the flange and had been partially covered by deformed material from the casing. Stud No. 2 (enclosure (1)) failed through the root of a thread. Stud No. 3 which was in contact with the broken out portion of the cylinder (enclosure (2)) did not break, but was bent along the plane of the diagonal between studs nos. 1 and 3. No damage other than a slight evidence of wear was apparent on stud no. 4, although chips of aluminum were found embedded in the threads.

3. Enclosures (3) and (4) are illustrations of the fracture faces of the section of the case casting that broke out. Wear is evident in that section which was forced past the flange stud (enclosure (4)). The fracture face appears granular with no evidence of a gradual propagation of failure, indicating an abrupt failure. Porosity was observed in these sections. Enclosure (5) illustrates the degree and distribution of the porosity observed in the longitudinal and transverse sections adjacent to the fracture. The smaller section is that taken just below the surface parallel to the fracture face.

4. Enclosure (6) shows the fracture face of stud no. 1. Failure occurred through the cross-section of the stud beginning at the thread root.

APPROVED F. S. Williams, By direction	APPROVED W. J. Fedyn, Head Physical Metallurgy Branch	REPORTED BY M. Raefsky Test Engineer
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NAVY-DPPO AND-PHILA. PA

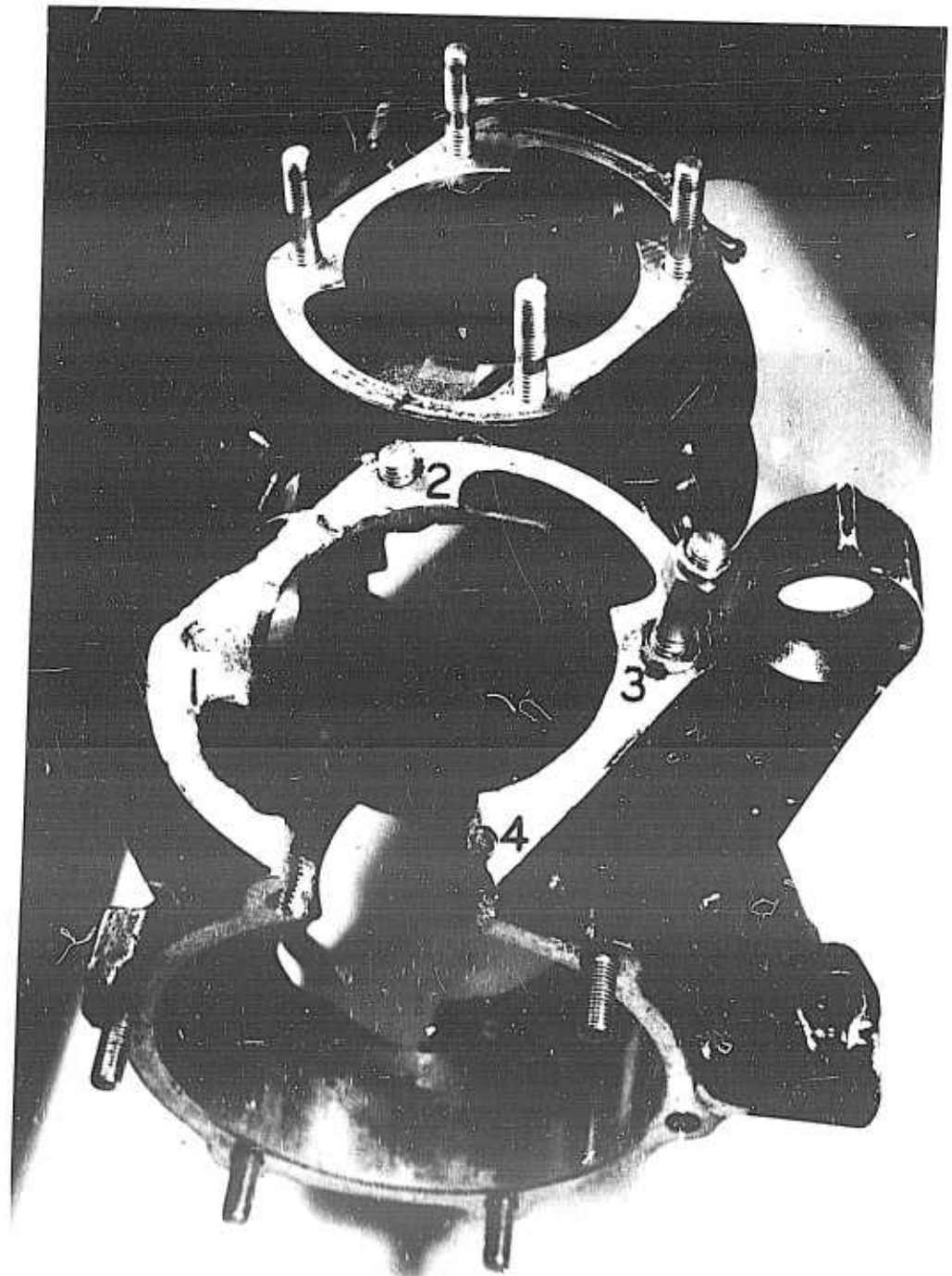
Plastic deformation may be seen on the extreme left side of the fracture face. The remainder of this face shows the characteristic oyster shell markings associated with fatigue failure. Microscopic examination of a longitudinal section of stud no. 1 revealed the presence of small cracks at the roots of several threads. This condition was not observed in a similar examination of the other studs. Enclosure no. 7 shows a crack located in the thread root adjacent to the thread through which failure occurred.

5. Enclosure (8) illustrates the microshrinkage porosity observed during the microscopic examination of the case casting.

6. While the case casting exhibited porosity, it is believed that the break-out in the flange area was a secondary failure. The primary failure is believed to be due to a fatigue failure in stud no. 1 (see enclosure (1)). Evidence for this may be seen in the cracks at the thread roots and fracture face of stud no. 1. In view of the fact that all the studs were found to be free from microstructural defects and were otherwise metallurgically sound, it is suggested that the fatigue failure of stud no. 1 was precipitated by the cyclic loads of engine operation. Following the failure of stud no. 1, and with the continuing operation of the engine, stud no. 2 and the case flange failed almost simultaneously. This is evidenced by the fact that stud no. 4 was not damaged but did have particles of aluminum embedded in the threads. The motion of the moving piston then imparted a bending moment to stud no. 3, which by this time was the only stud holding the cylinder head. As may be seen by reference to enclosure (2), this stud bent backwards and to the right away from studs nos. 2 and 4. When the bending moments became too great, the cylinder casting failed.

7. While it is extremely difficult to predict whether a part will fail in fatigue, it must be assumed that cyclic stressing makes it susceptible to failures of this type. Considering that operational stresses are not completely predictable from design criteria, it is recommended that the performance of the engine be investigated with this in view. Additionally, because of the fatigue failure observed in stud no. 1, it is suggested that attention be given to the proper tightening of the cylinder studs in the assembly of the engine. A loose stud results in a larger range of cyclic stress which leads to premature failure by reducing the fatigue limit of the stud.

8. This report completes the work requested by reference (a).



MAG - X Approx.

GENERAL VIEW OF FRACTURED ENGINE CASE

Note Wear on Left Side of Cylinder Mounting Flange

PHOTO NO: CAN-315786(L)-1-59

ENCLOSURE (1)



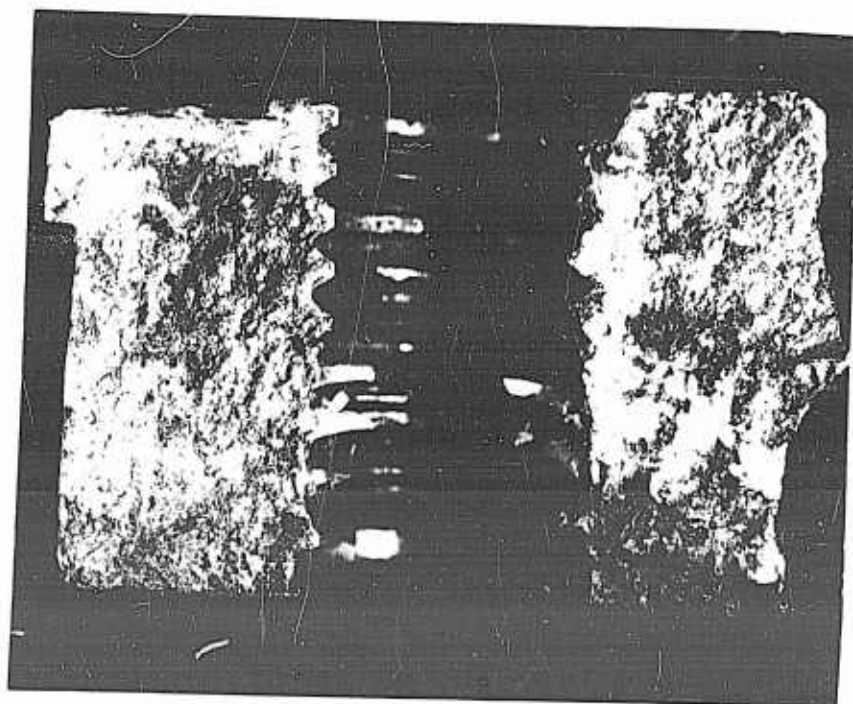
MAG - X Approx.

GENERAL VIEW OF FRACTURED CYLINDER

The Stud shown in this illustration is Stud #4

PHOTO NO: CAN-315787(L)-1-59

ENCLOSURE (2)

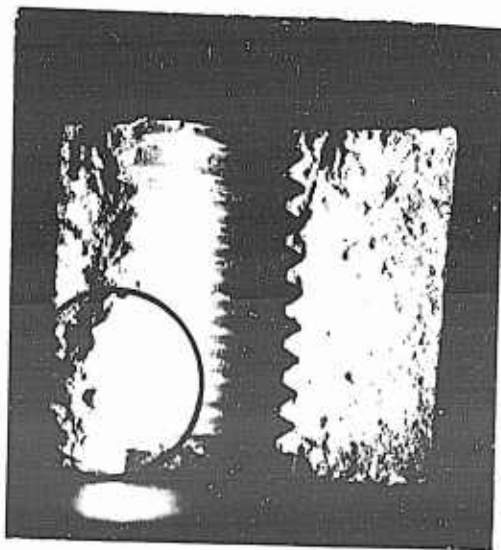


MAG - 4₂X Approx.

FRACTURE FACE AT CYLINDER STUD HOLE

PHOTO NO: CAN-315788(L)-1-59

ENCLOSURE (3)



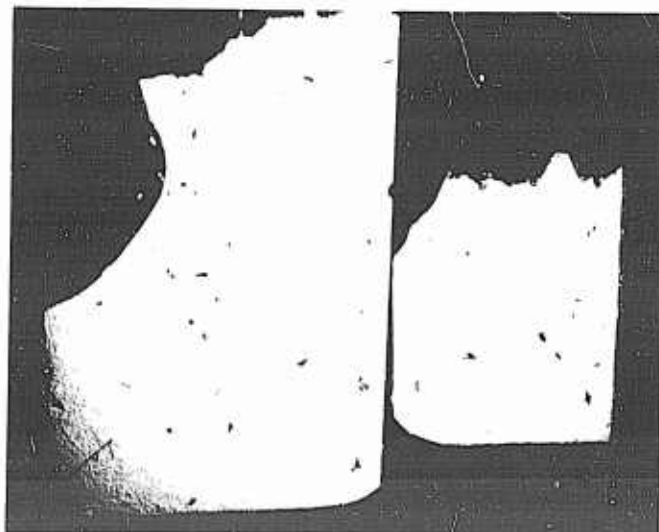
MAG - 3 X Approx.

FRACTURE FACE AT FLANGE STUD HOLE

Note wearing (encircled).

PHOTO NO: CAN-315789(L)-1-59

ENCLOSURE (4)



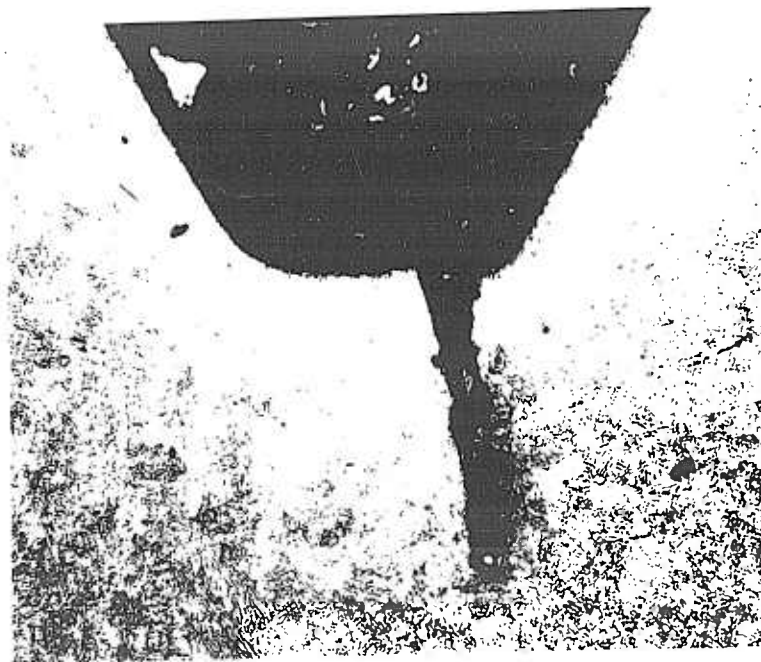
MAG - 3X Approx.

POROSITY IN FRACTURE FACE

Smaller Section on Left is Taken Parallel to Fracture Face, Section on Right is Longitudinal to Fracture face.

PHOTO NO: CAN-315790(L)-1-59

ENCLOSURE (5)



MAG - 210X

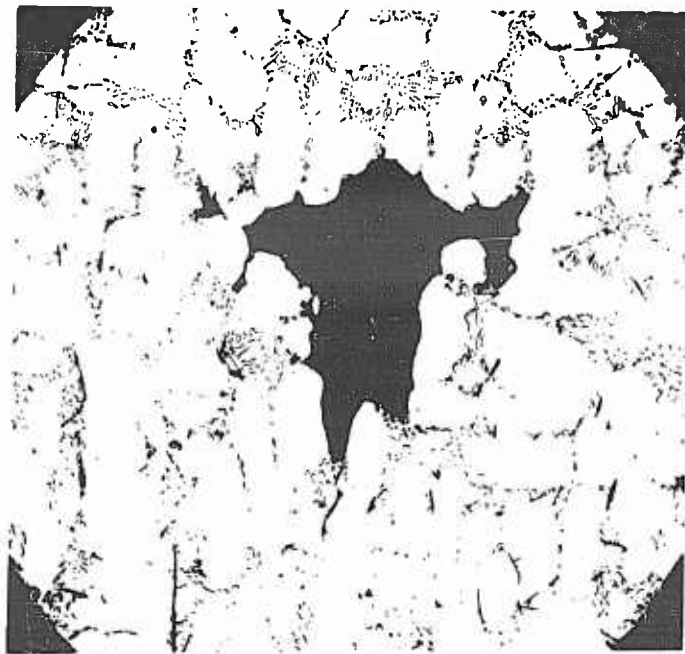
2% Nital Etch

CRACK IN STUD THREAD ROOT

Note inclusion at base of crack

PHOTO NO: CAN-315792(L)-1-59

ENCLOSURE (7)



MAG - 120X

10% Oxalic Acid

MICROSTRUCTURE OF ENGINE CASE, SHRINKAGE CAVITY

Note Distribution of Second Phase in Matrix. The second phase has been identified as an Al-Si eutectic.

PHOTO NO: CAN-315793(L)-1-59

ENCLOSURE (8)